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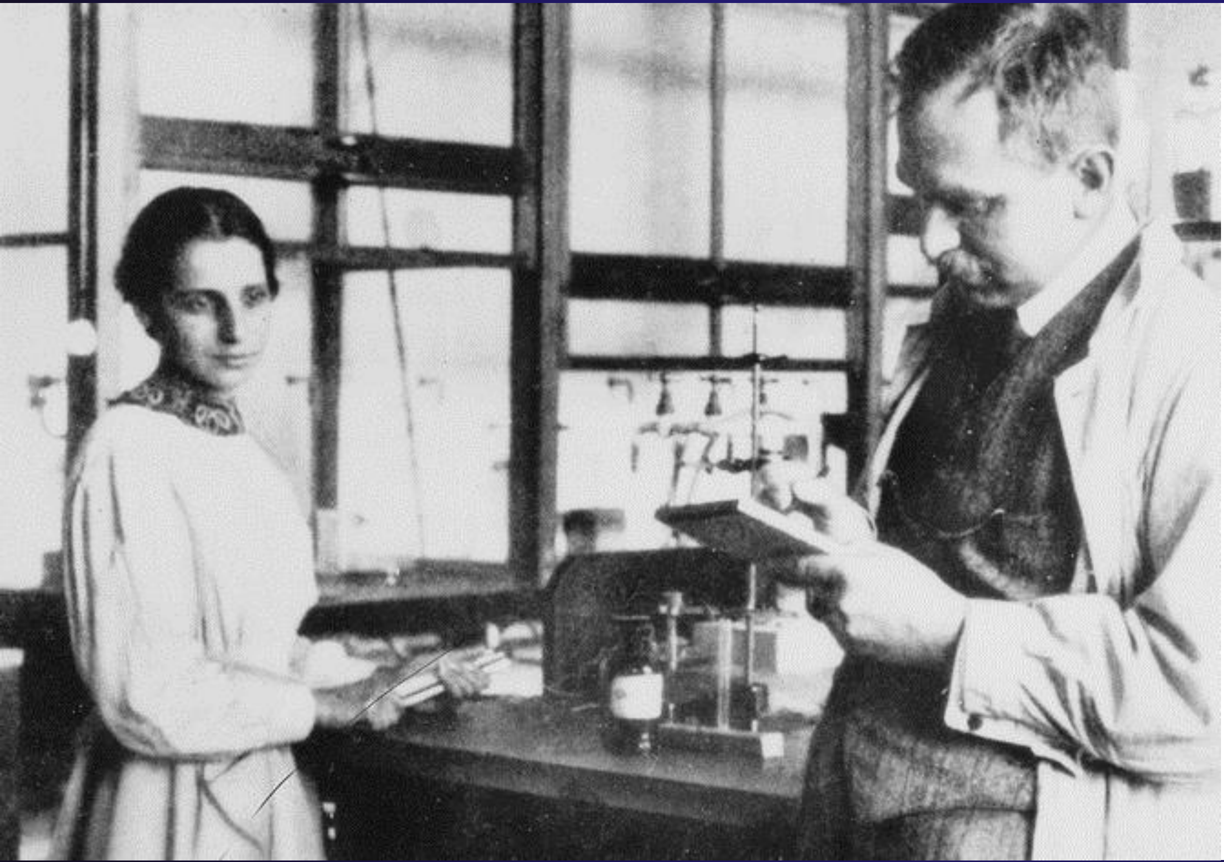
Nuclear Engineering Primer for Non-Nuclear Engineers



Katie Mummah

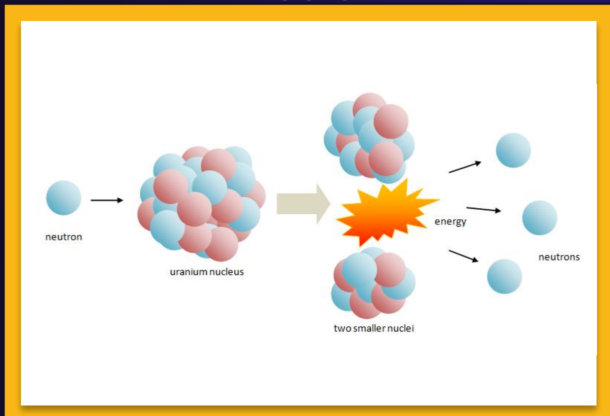
NEN-5, Systems Design & Analysis

7/10/2017

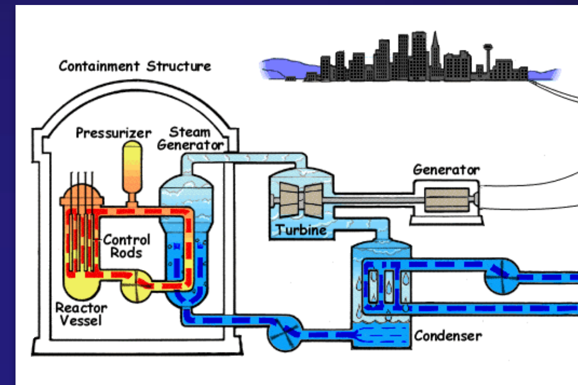
National Nuclear Security Administration

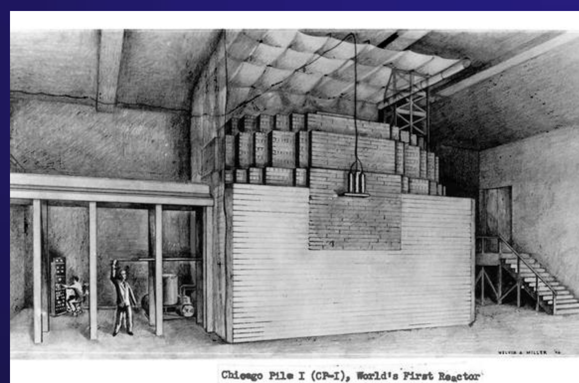
Operated by Los Alamos National Security, LLC for the U.S. Department of Energy's NNSA

Fission



Light Water Reactors



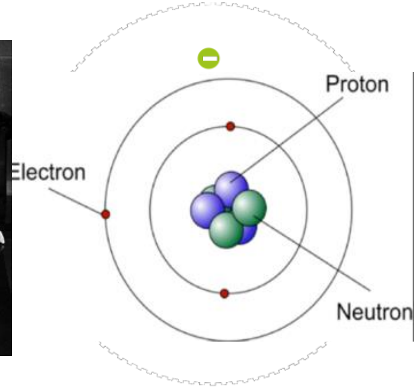


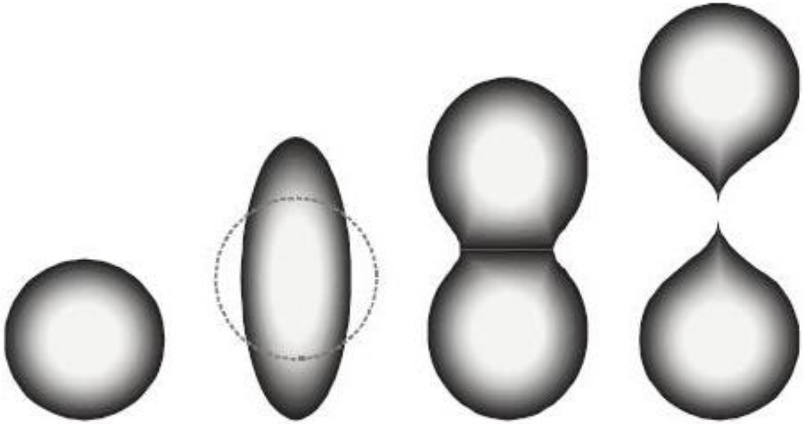
History of Nuclear Reactors

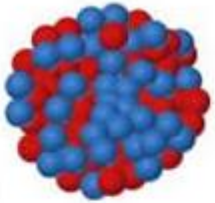
TerraPower
NuScale Power
Xe
Flibe Energy
Transatomic Power Corporation
Terrestrial Energy

Future of Nuclear Power

Fission



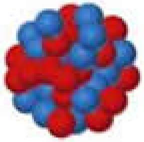


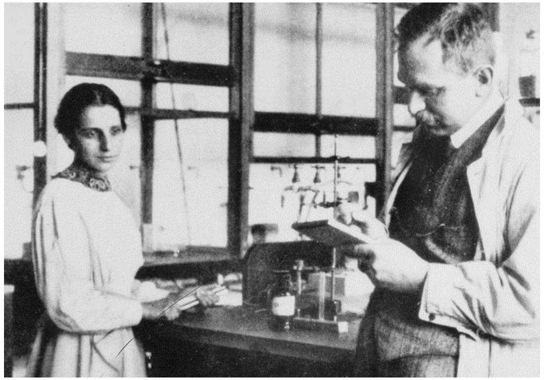


$^{235}_{92}U$

???

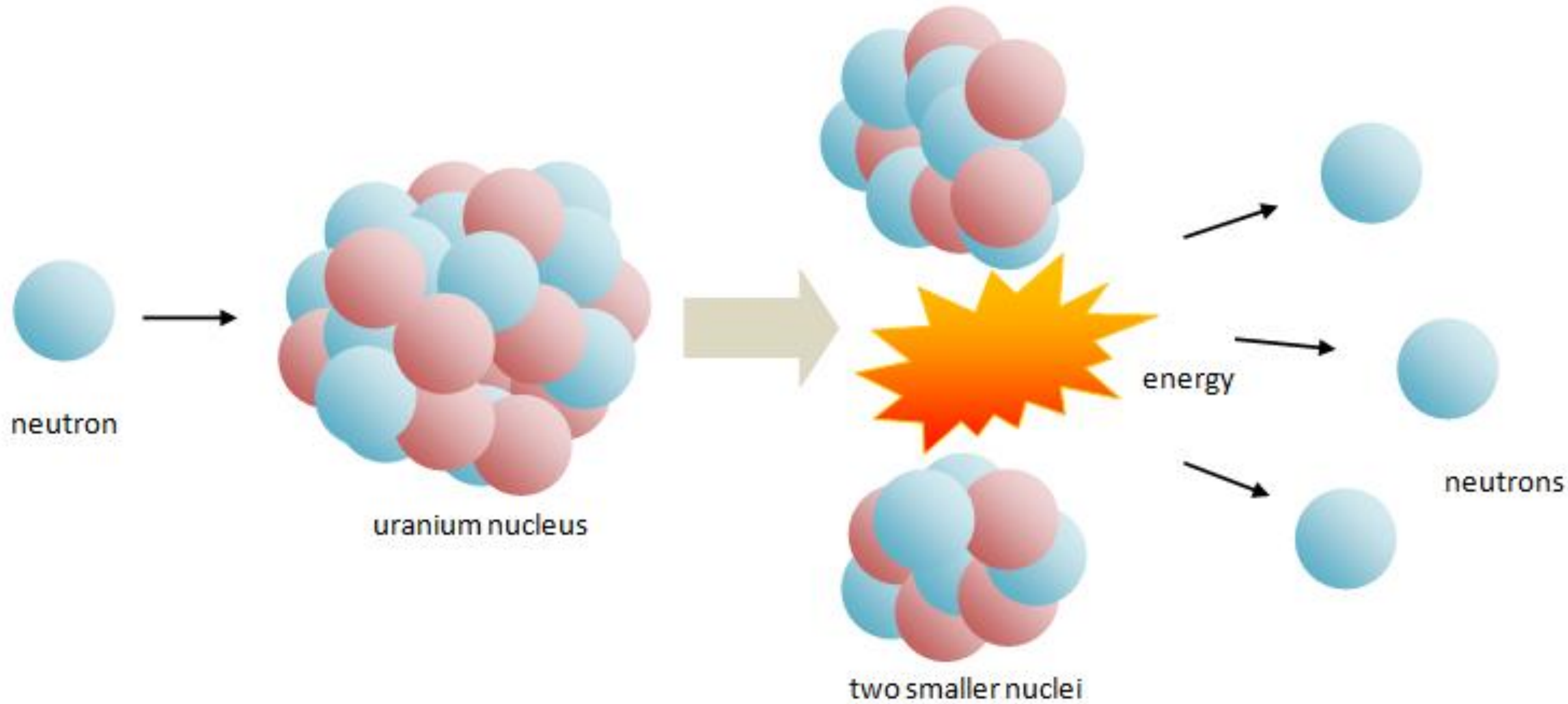
$^{141}_{56}Ba$





1934, Ida Noddack

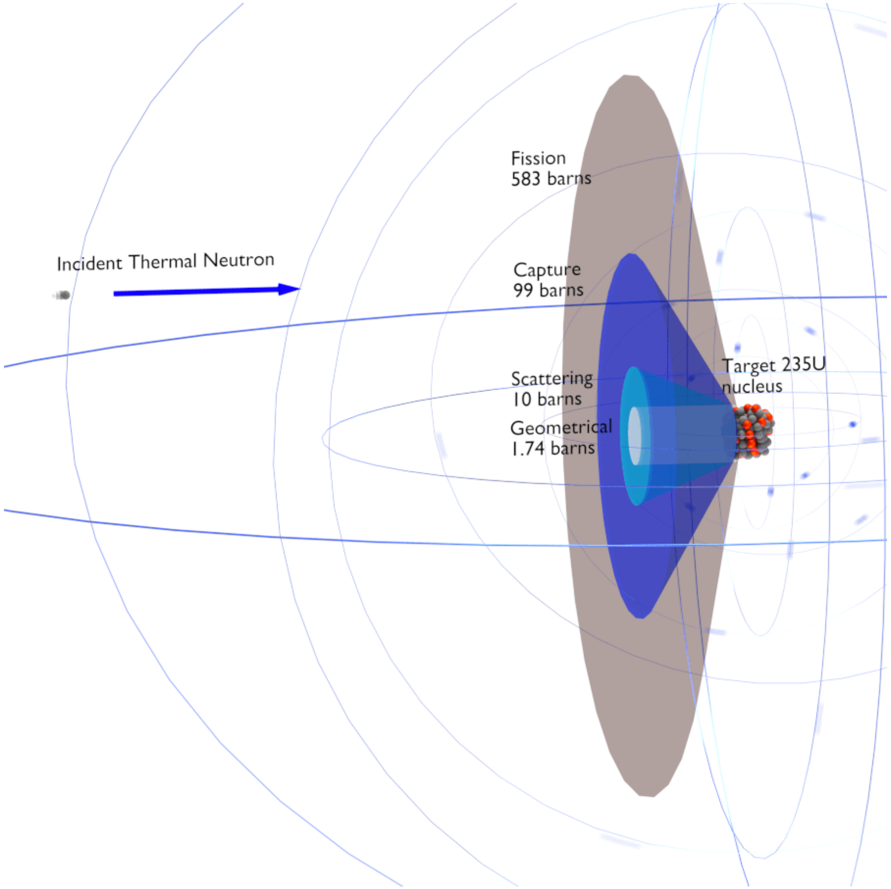
Fission



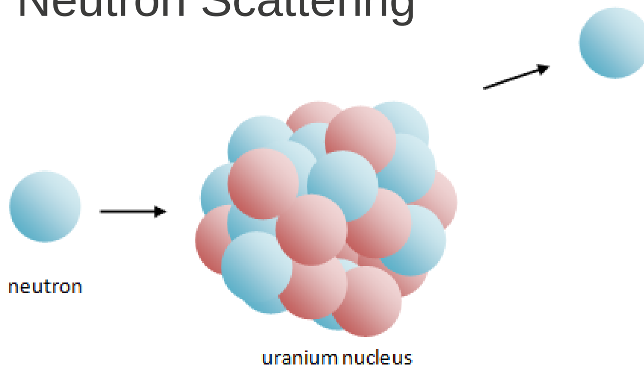
neutron
uranium nucleus
energy
two smaller nuclei
neutrons

However, fission is not the only possible interaction between a neutron and a nucleus

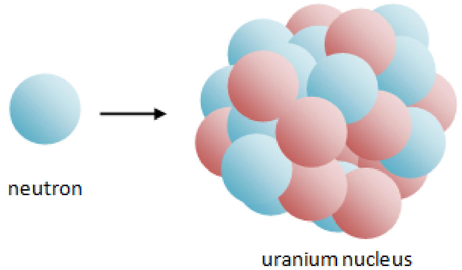
Fission



Neutron Scattering

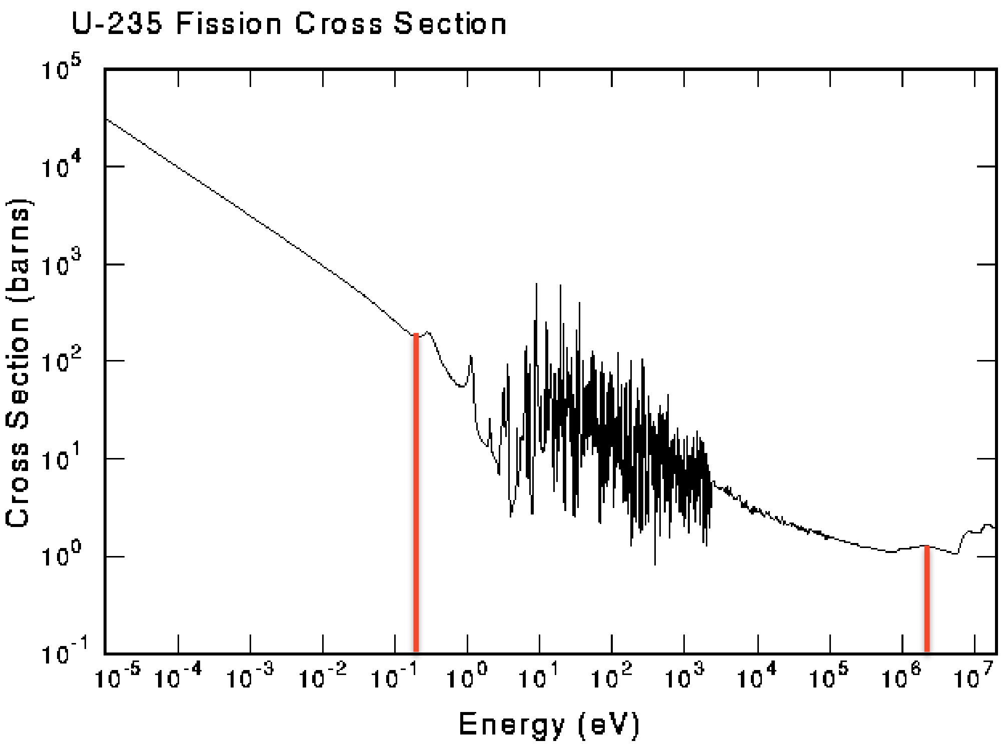


Neutron Absorption

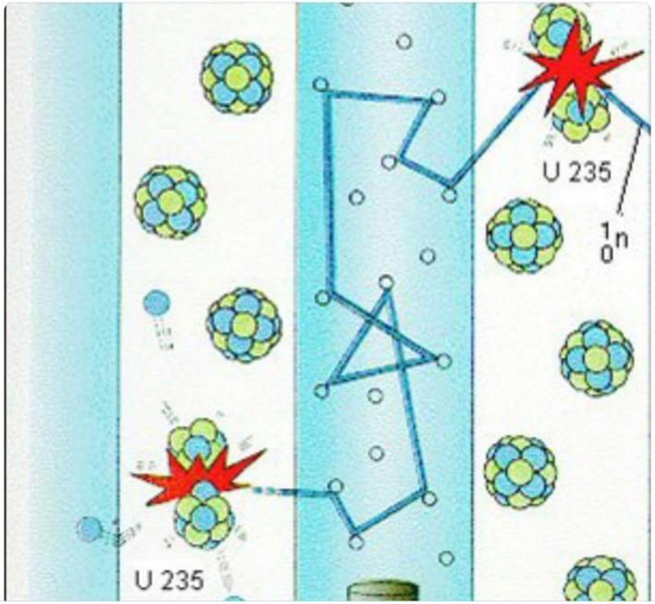


Neutron moderation is needed for reactors using ^{235}U

Fission



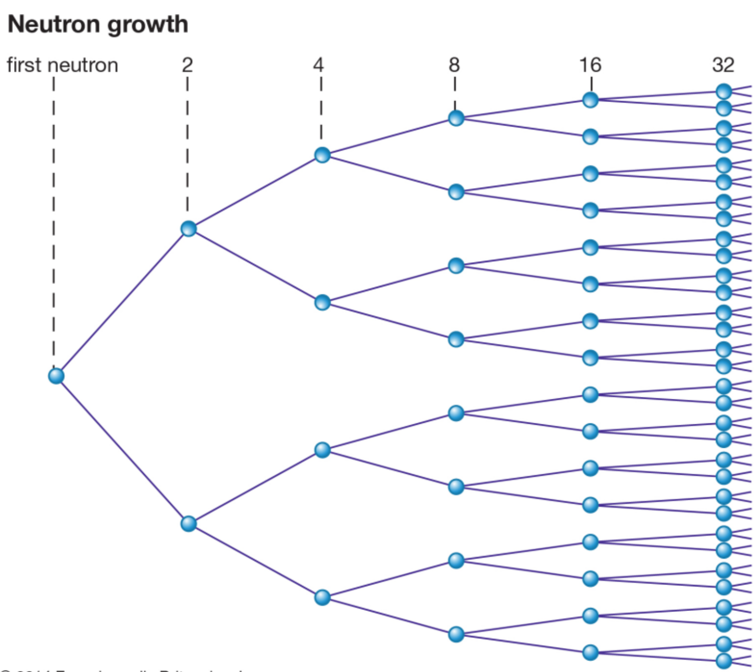
Her: Come over
Me: I'm traveling too fast, the cross section is too low
Her: I'm fissile
Me:



For a controlled chain reaction, k=1.00 is desired

Fission

$$k_{eff} = \frac{\text{neutron production from fission in one neutron generation}}{\text{neutron absorption and leakage in the preceding neutron generation}}$$



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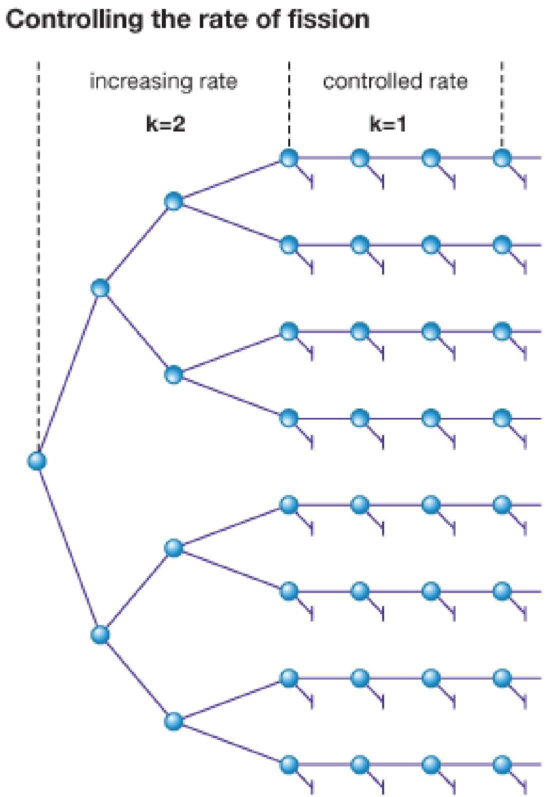

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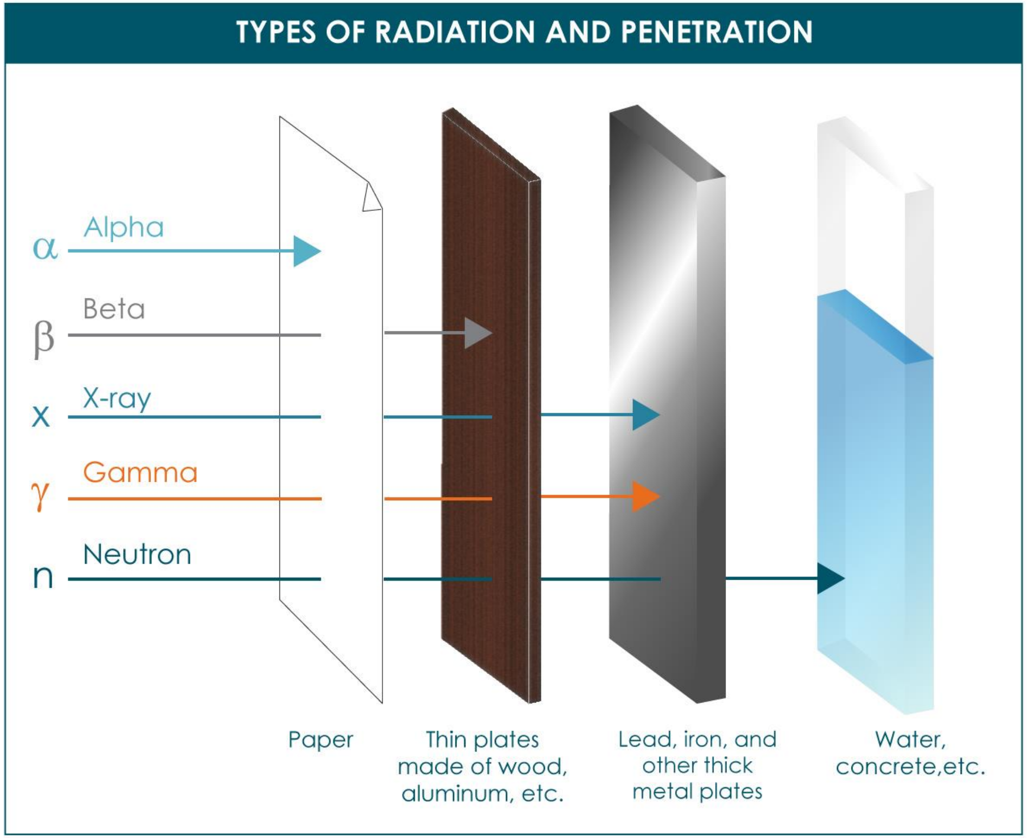
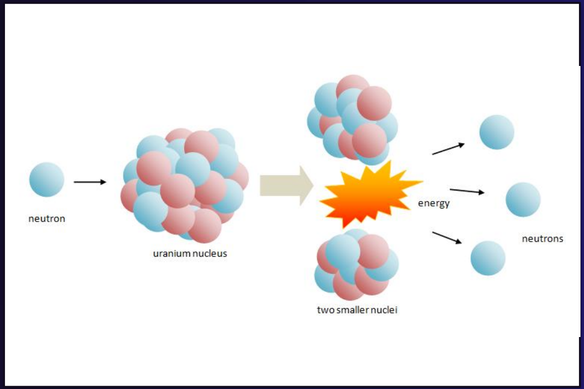
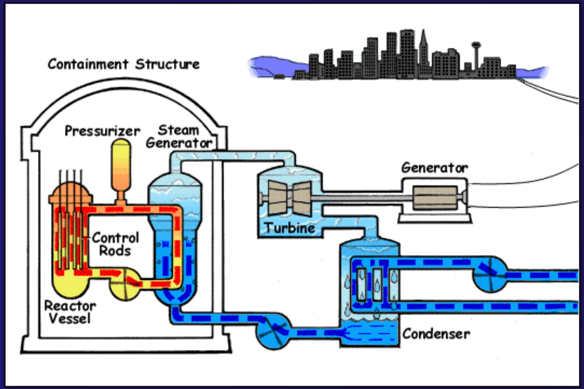
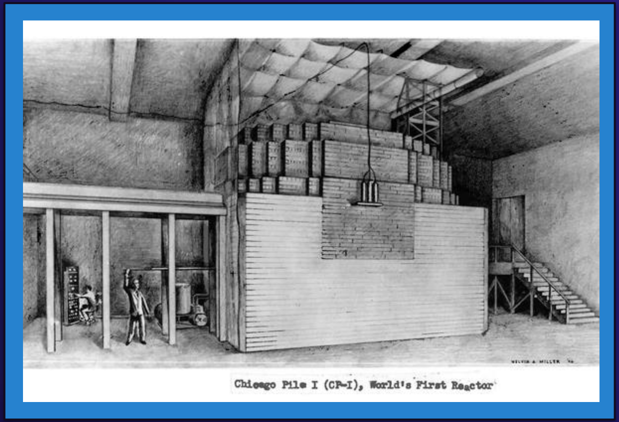

TYPES OF RADIATION AND PENETRATION
α Alpha
β Beta
x X-ray
γ Gamma
n Neutron
Paper
Thin plates made of wood, aluminum, etc.
Lead, iron, and other thick metal plates
Water, concrete,etc.

Fission



Light Water Reactors





History of Nuclear Reactors

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NuScale Power
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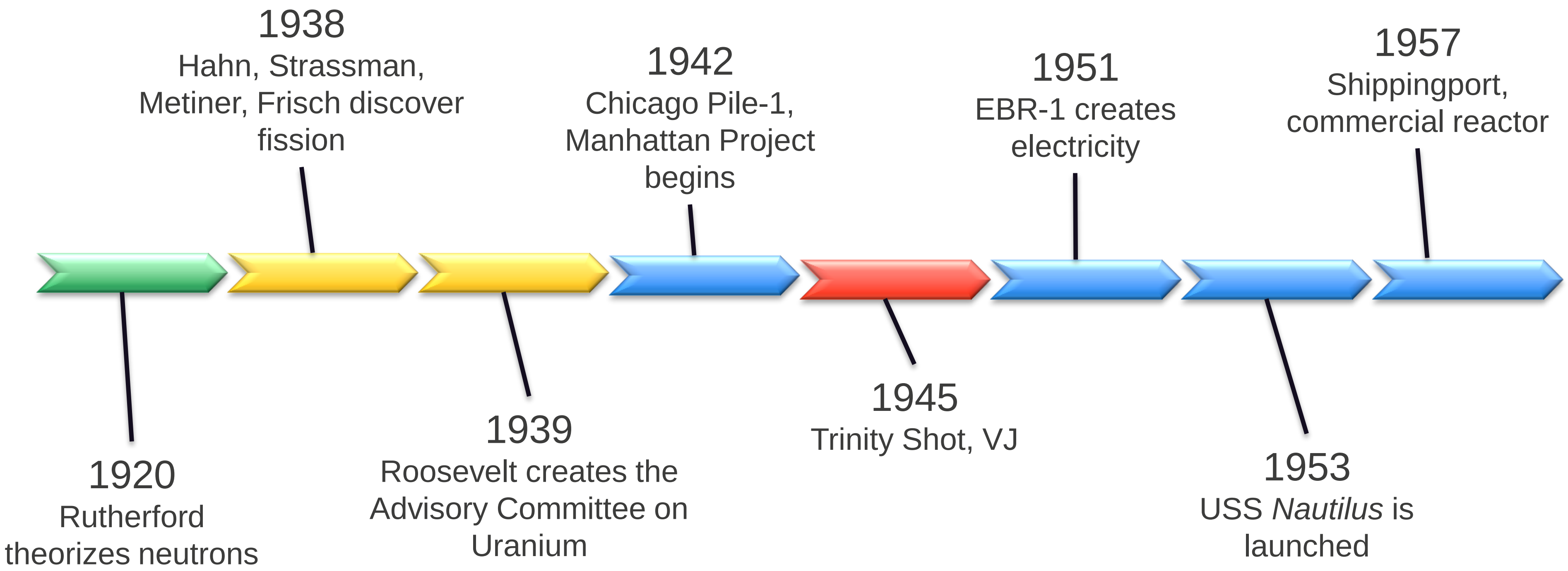
Terrestrial Energy

Future of Nuclear Power

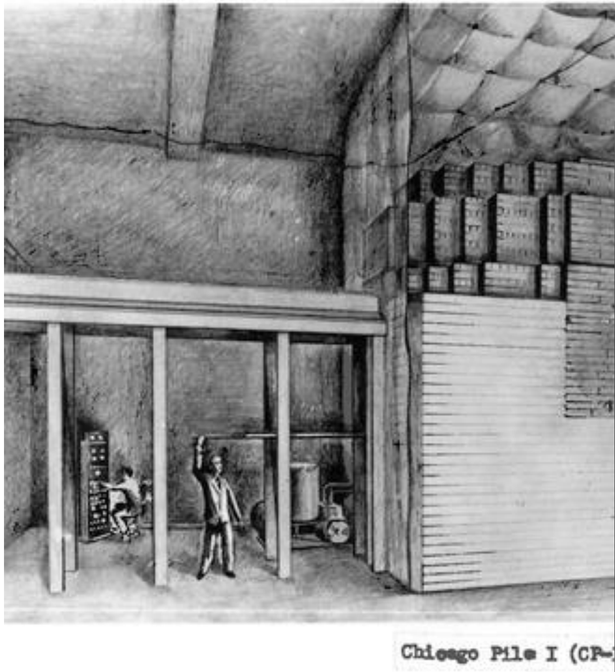
History


1920
Rutherford theorizes neutrons
1938
Hahn, Strassman, Metiner, Frisch discover fission
1939
Roosevelt creates the Advisory Committee on Uranium
1942
Chicago Pile-1, Manhattan Project begins
1945
Trinity Shot, VJ
1951
EBR-1 creates electricity
1953
USS *Nautilus* is launched
1957
Shippingport, commercial reactor

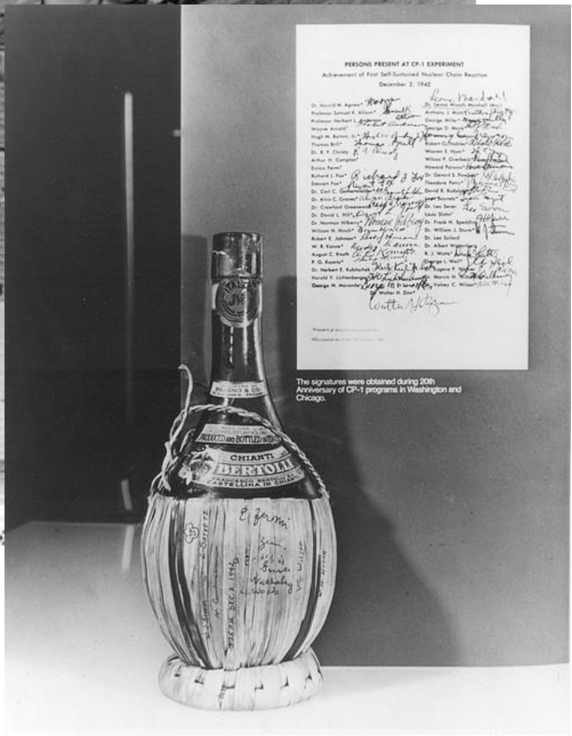
Chicago Pile-1 was the world's first (man-made) self-sustaining nuclear reaction

History

Earlier piles produced disappointing *k* of 0.87, eventually 0.918.

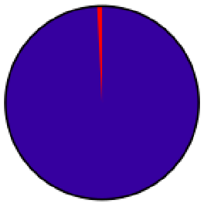


k=1.0006, 0.5 W for 4.5 min

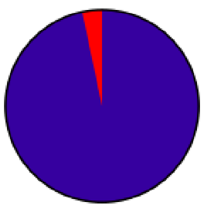


The first electricity-producing reactor, EBR-1, was actually build to prove the concept of fuel breeding

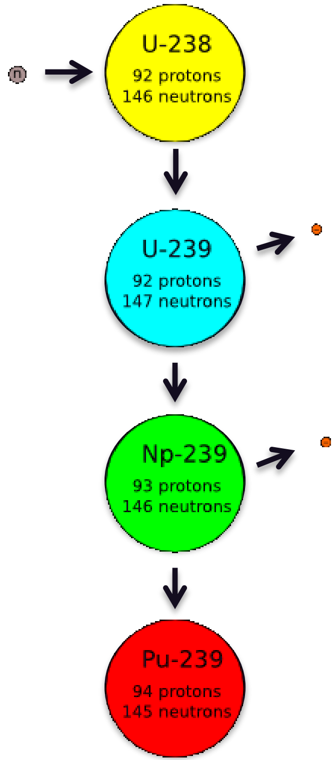
History



Natural uranium
> 99.2% U-238
0.72% U-235

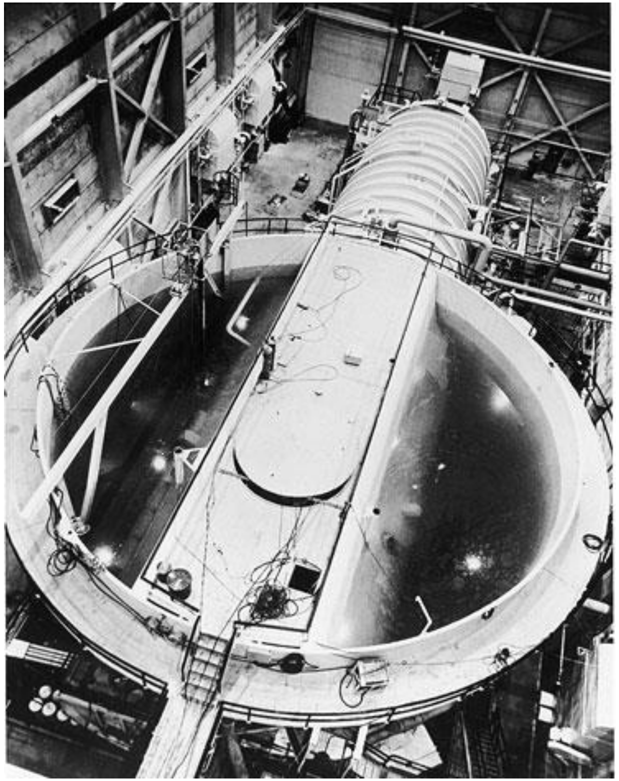


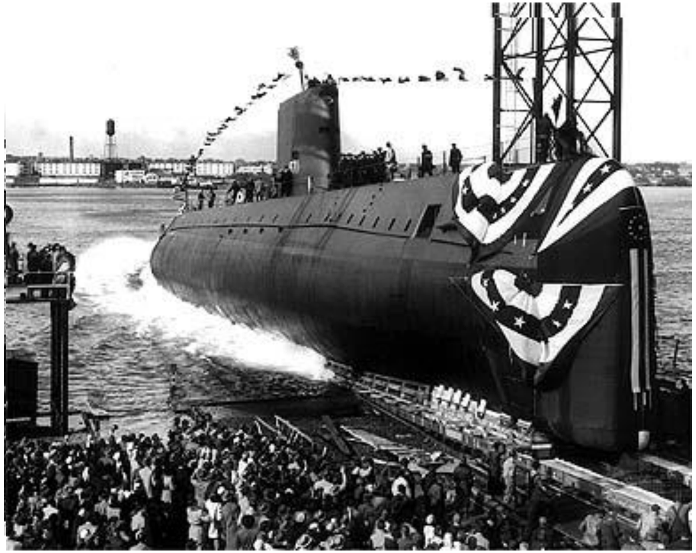
Low-enriched uranium
(reactor grade)
3-4% U-235



When Admiral Hyman Rickover chose LWRs for the USS Nautilus, he set the course for commercial plants, too

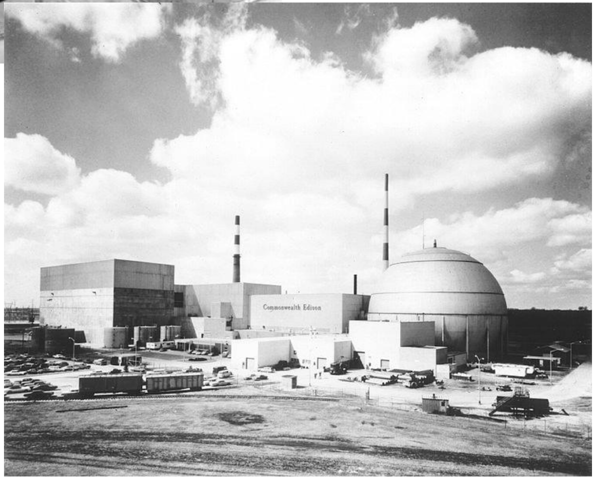
History



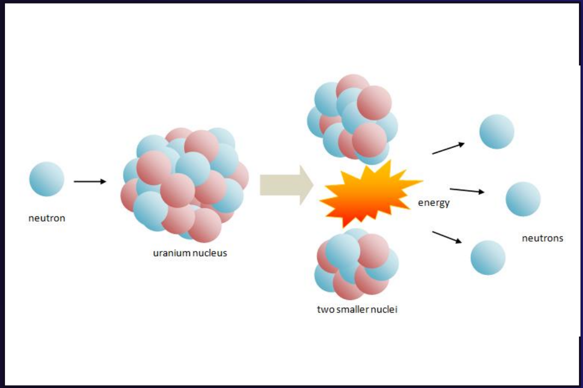


Shippingport, Yankee Rowe

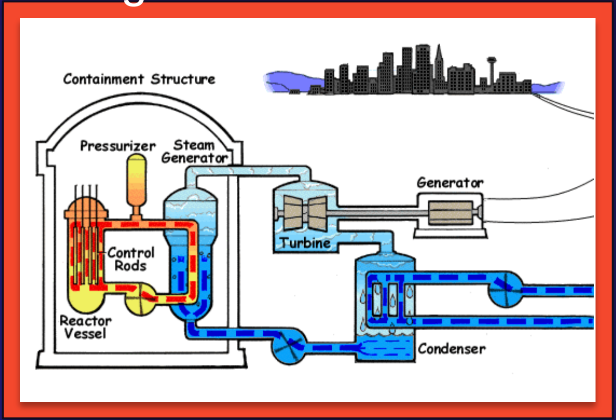
History

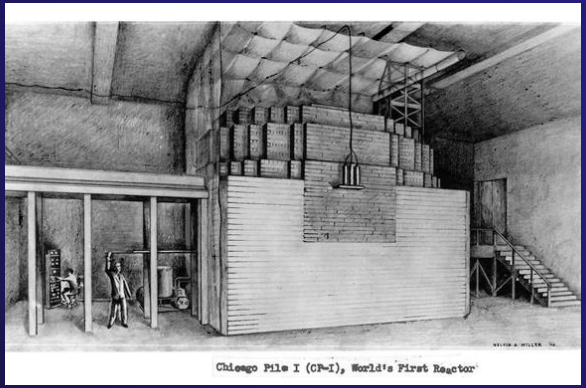


Fission



Light Water Reactors

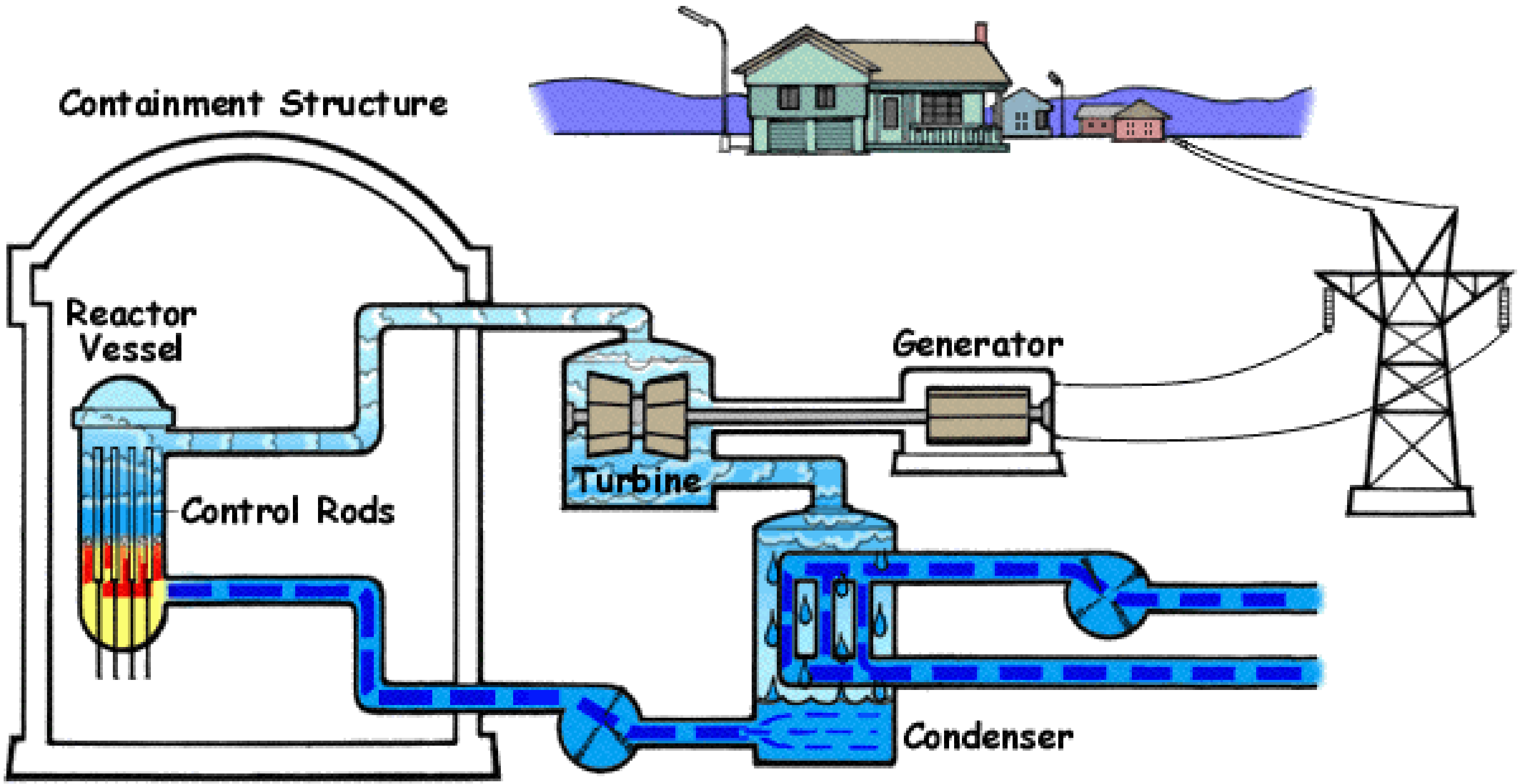



Chicago Pile I (CP-1), World's First Reactor

History of Nuclear Reactors

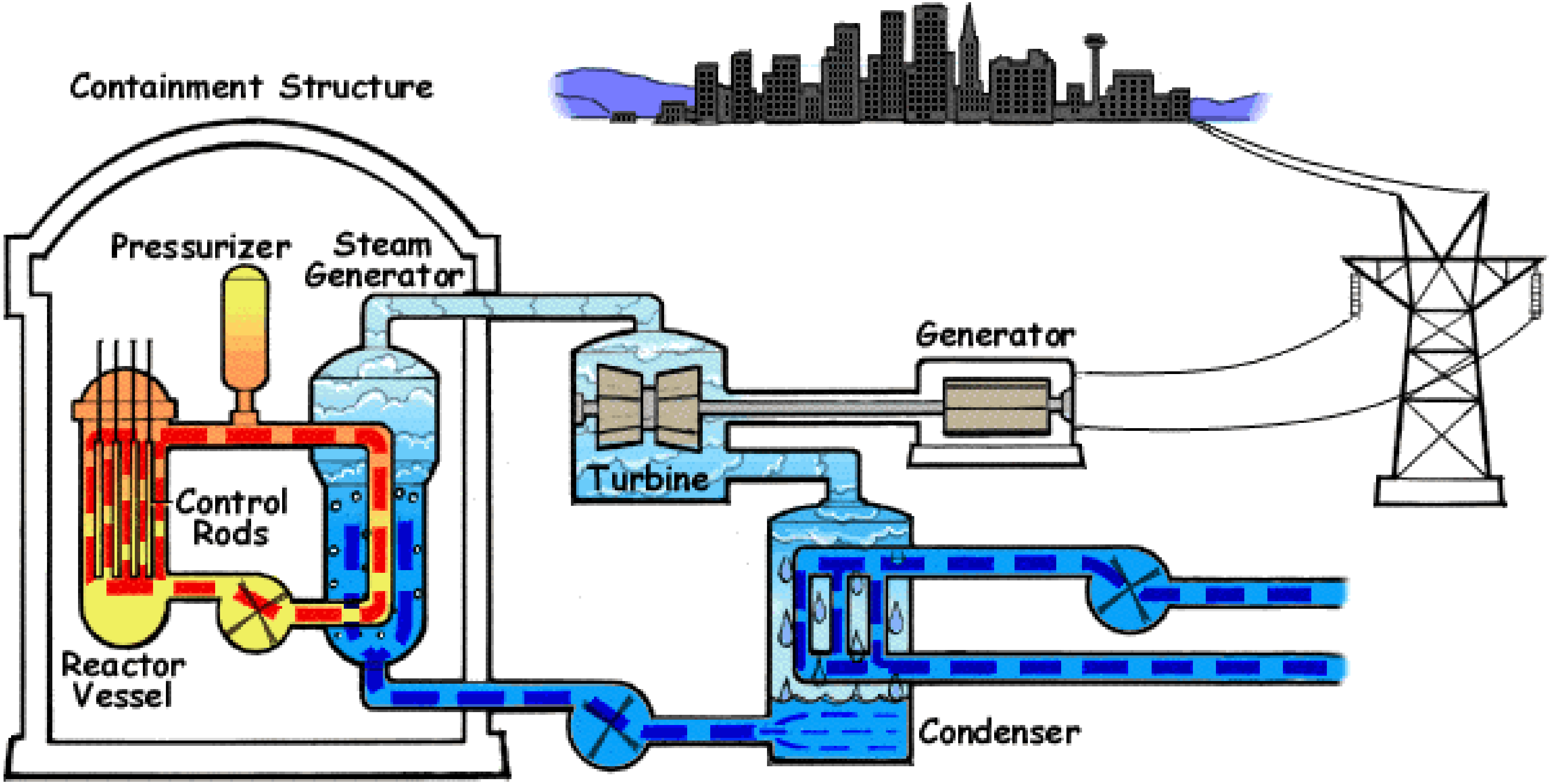
Future of Nuclear Power

LWRs



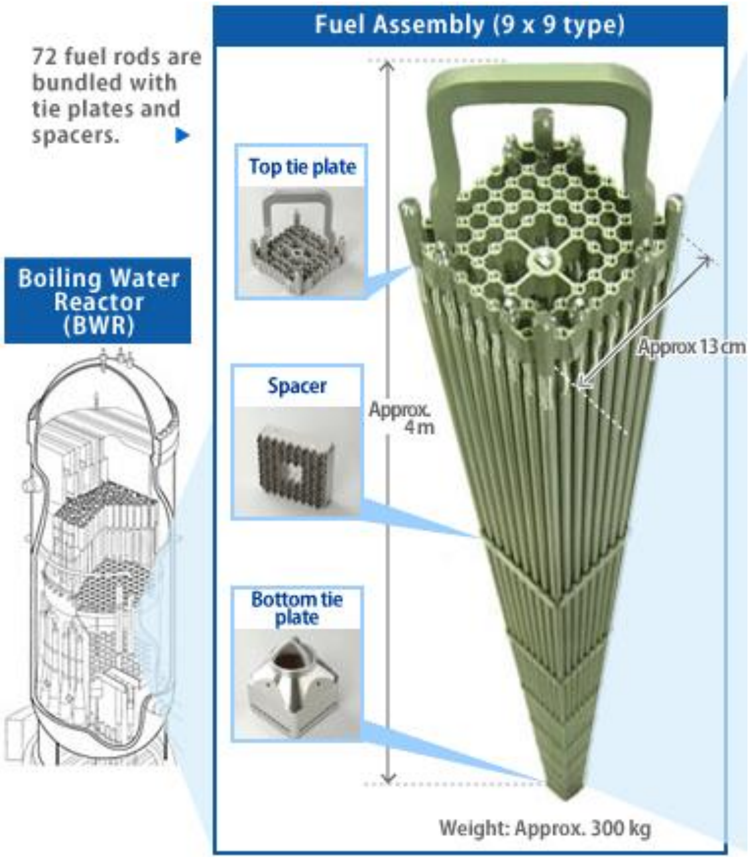
Containment Structure
Reactor Vessel
Control Rods
Turbine
Generator
Condenser

LWRs

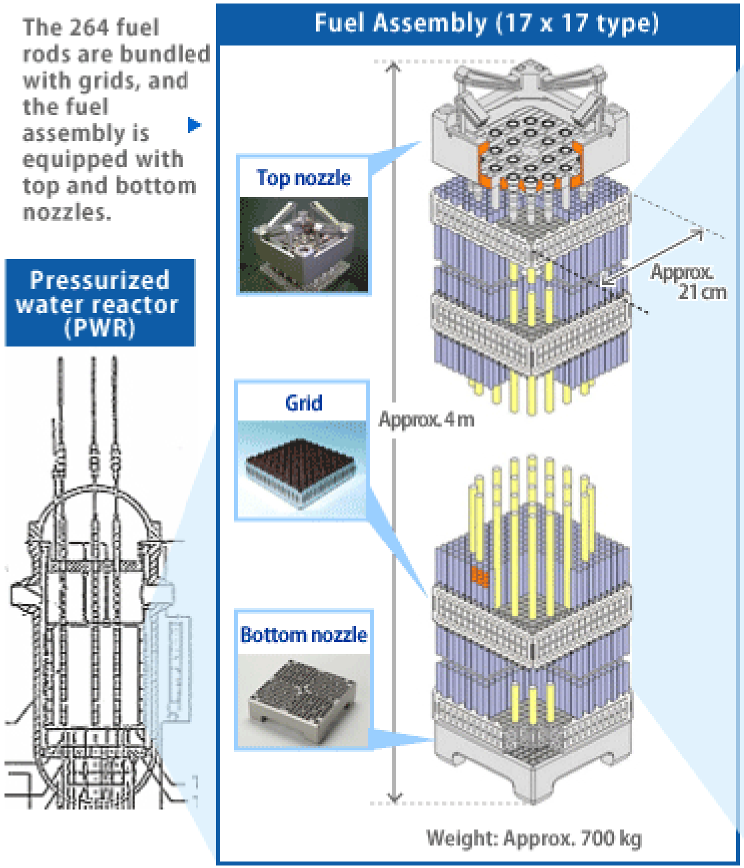

Containment Structure
Pressurizer
Steam Generator
Control Rods
Reactor Vessel
Turbine
Generator
Condenser

LWRs

700-800 assemblies/reactor



150–250 assemblies/reactor



PWRs have control rods that come down from the top, while BWRs have control blades from the bottom

LWRs

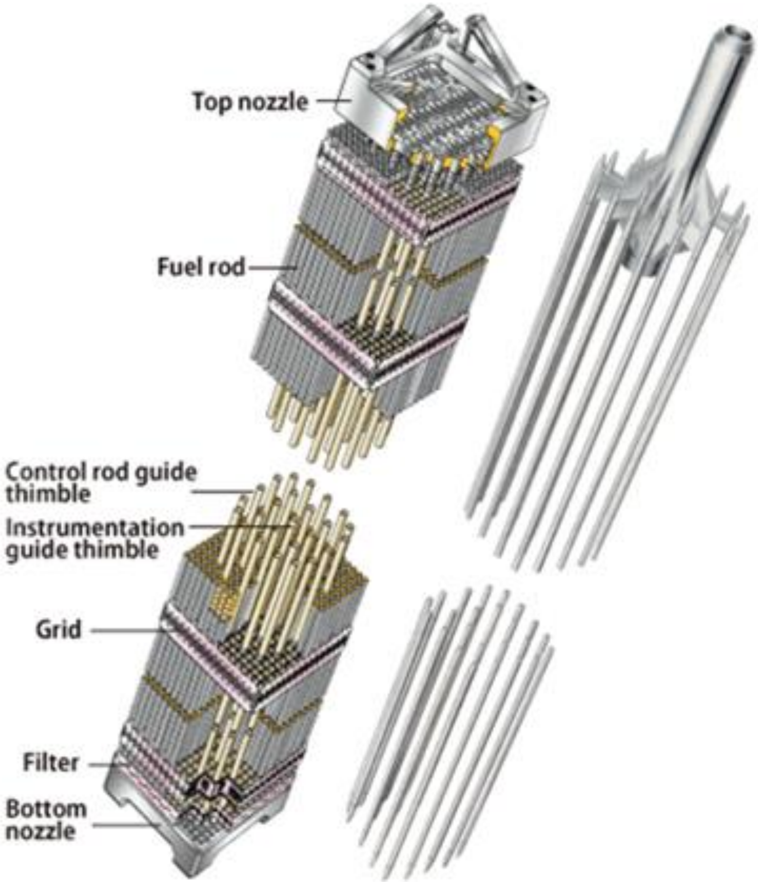
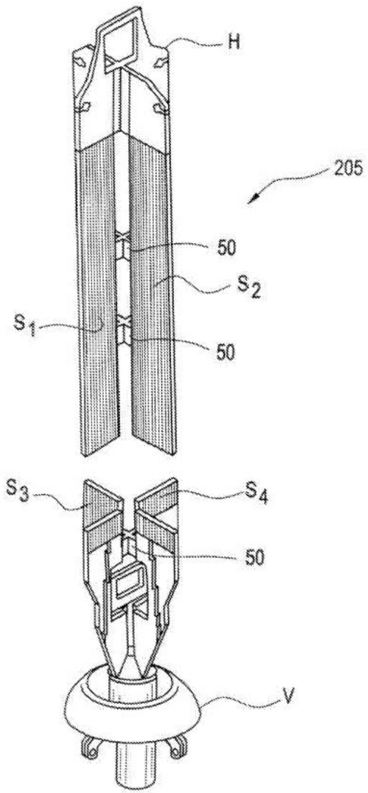
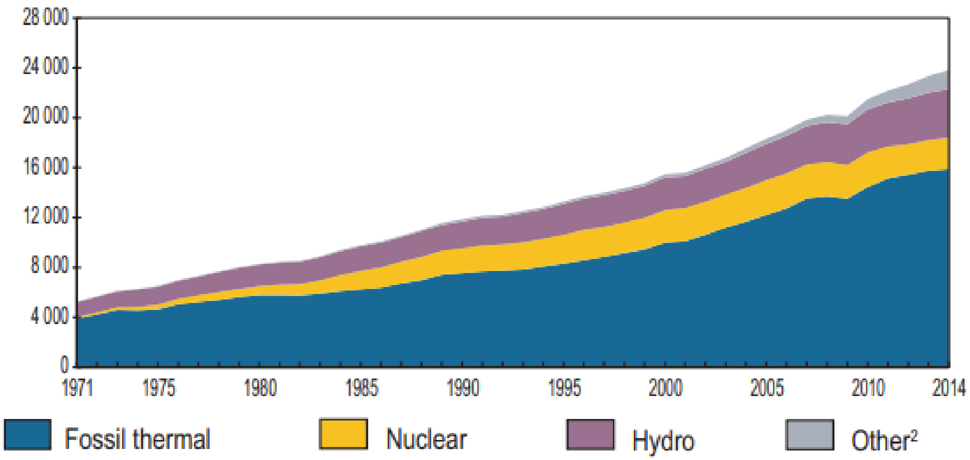


FIG. 5

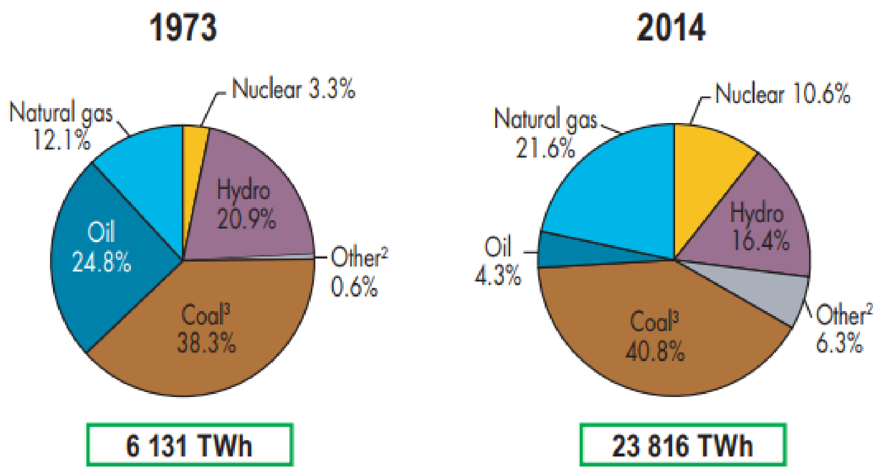


Nuclear has been a part of the world energy supply for decades

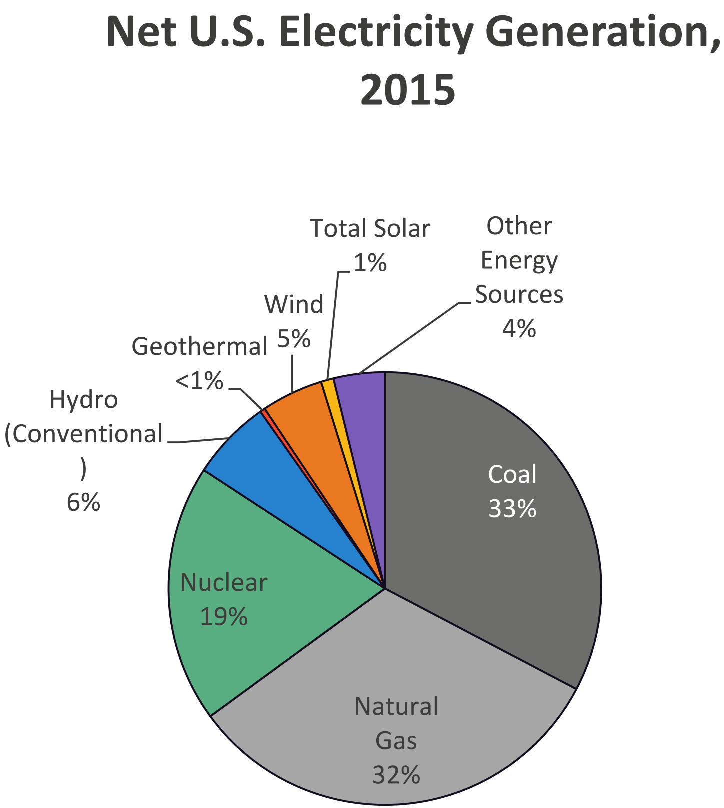
World electricity generation[1] from 1971 to 2014 by fuel (TWh)

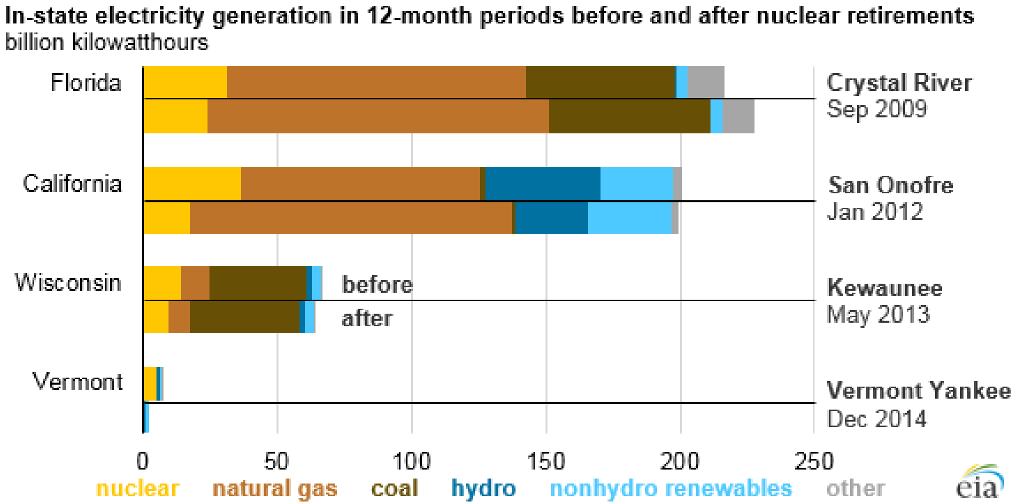


1973 and 2014 fuel shares of electricity generation[1]



Nuclear is an important source of carbon-free energy, and when it is closed, it's mostly replaced by nat gas



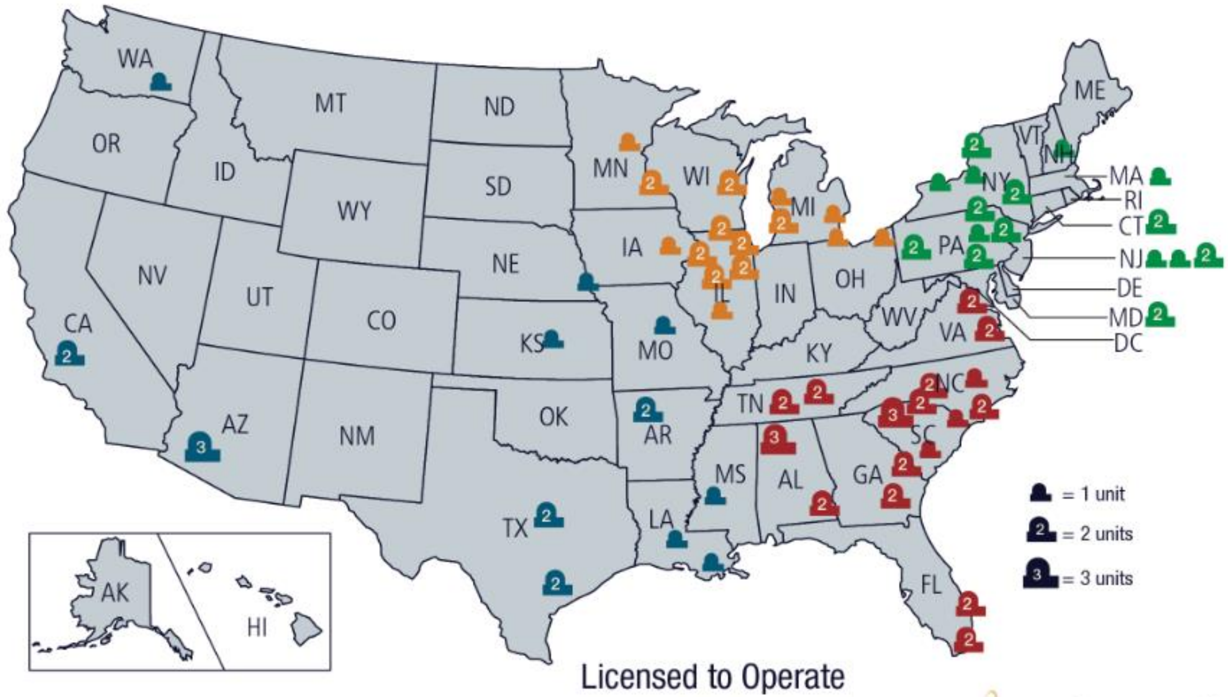


Data from

U.S. Energy Information Administration

LWRs

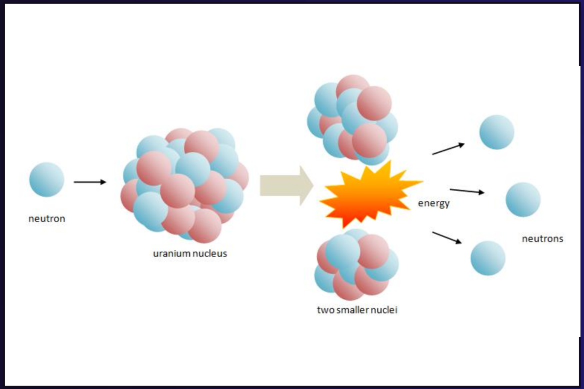
U.S. Operating Commercial Nuclear Power Reactors



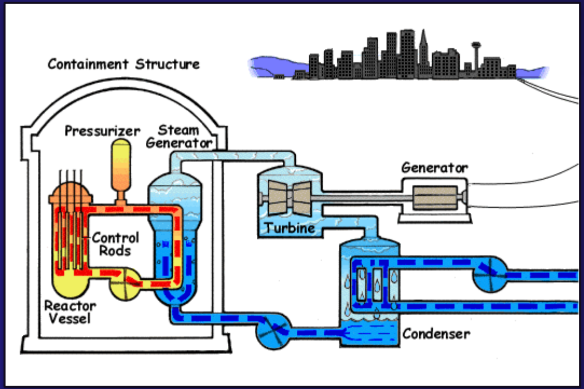
As of May 2017

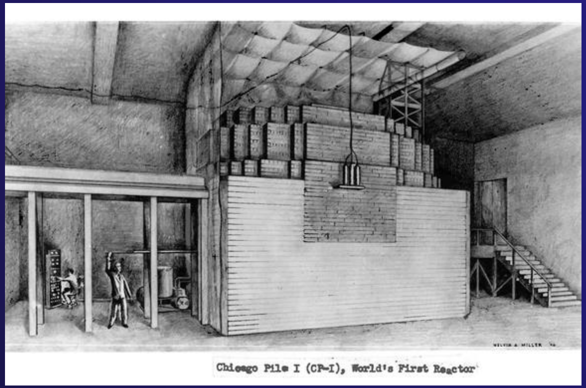
U.S.NRC
United States Nuclear Regulatory Commission
Protecting People and the Environment

Fission



Light Water Reactors



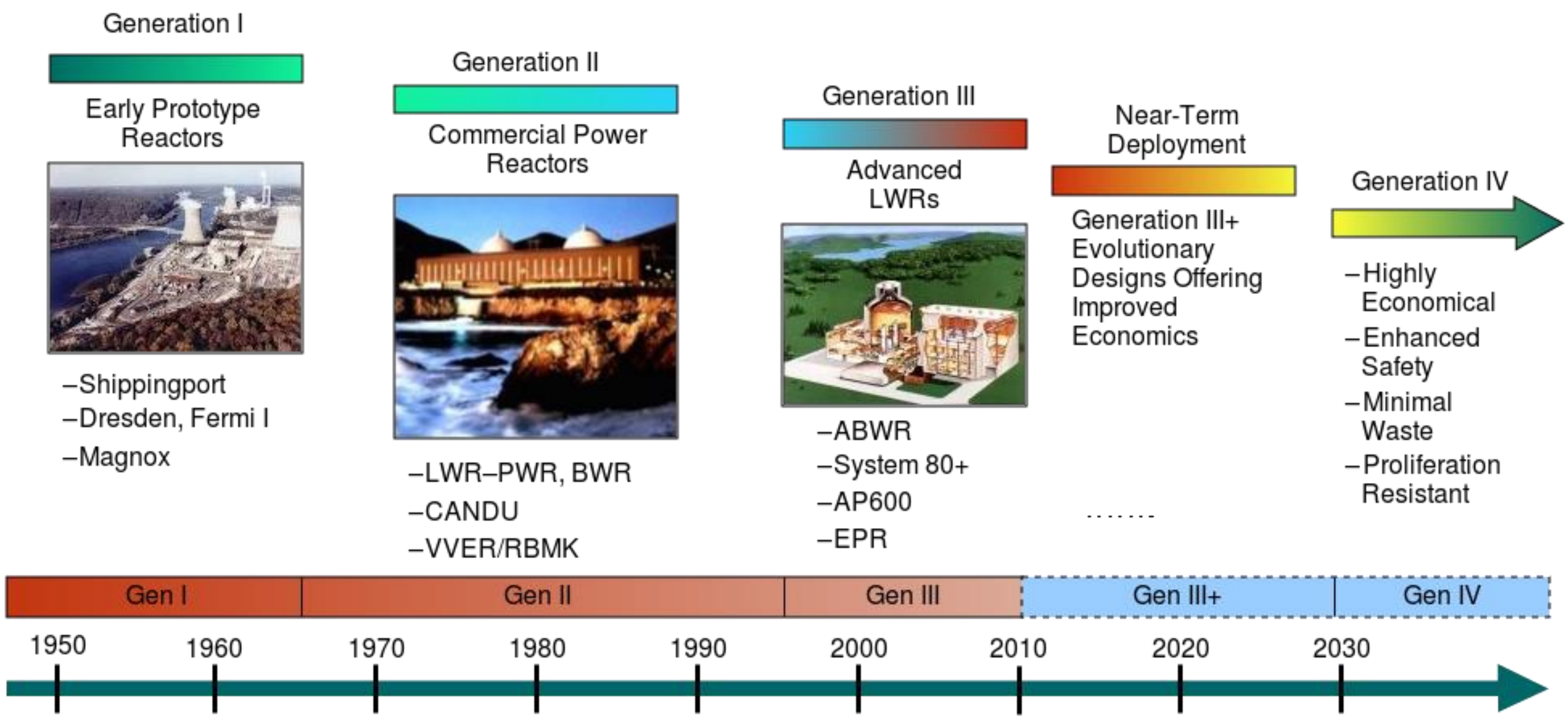

Chicago Pile I (CP-I), World's First Reactor

History of Nuclear Reactors

TerraPower
NuScale Power
X-energy
Flibe Energy
Transatomic Power Corporation
Terrestrial Energy

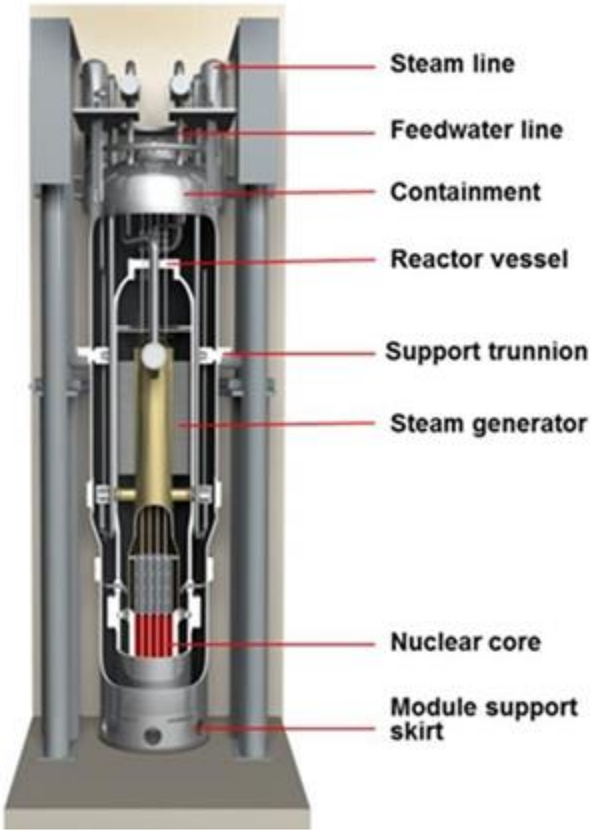
Future of Nuclear Power

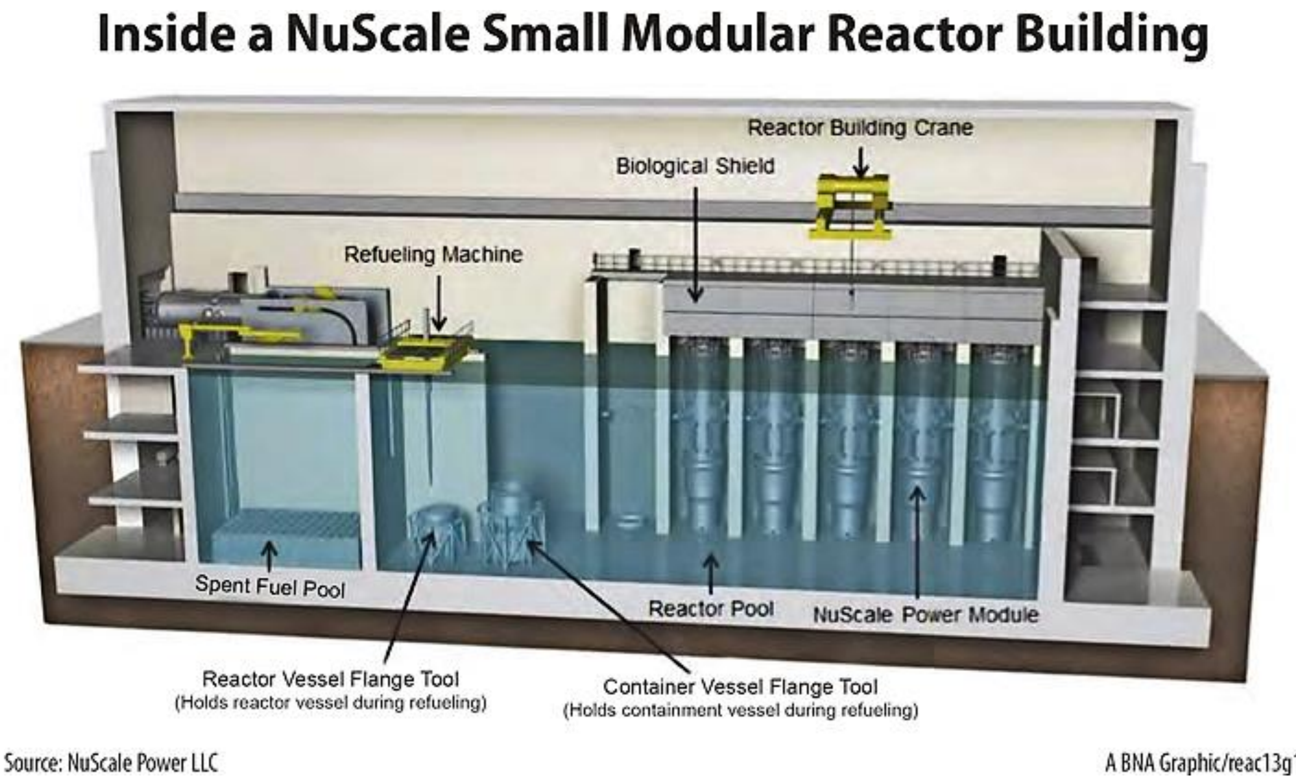
Generation IV: Nuclear Energy Systems Deployable no later than 2030 and offering significant advances in sustainability, safety and reliability, and economics



One of the most promising nuclear concepts is the SMR, including NuScale's 30 MW design

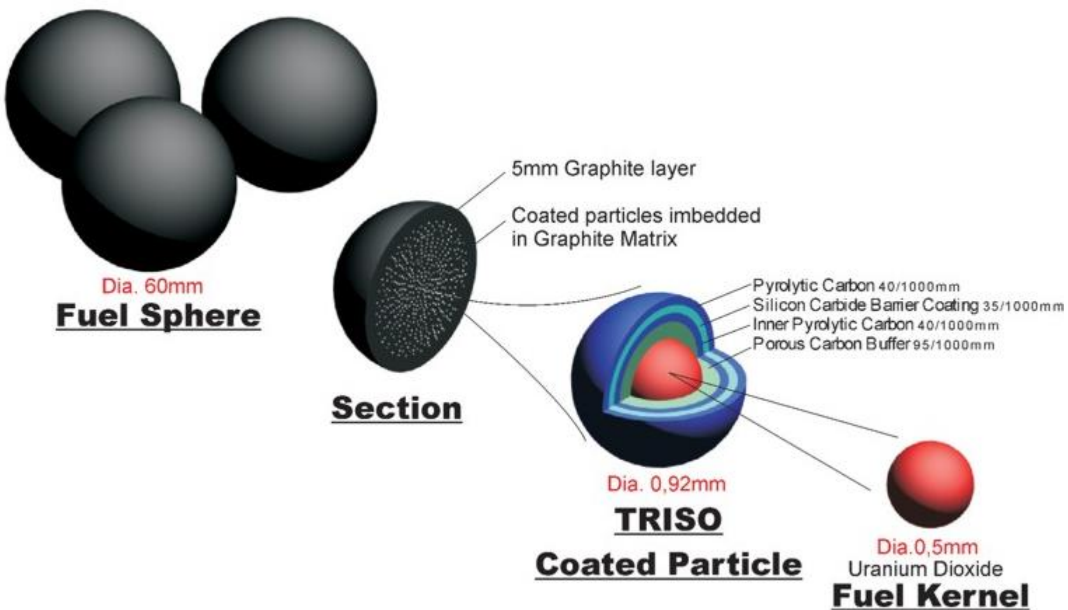
New Nuclear

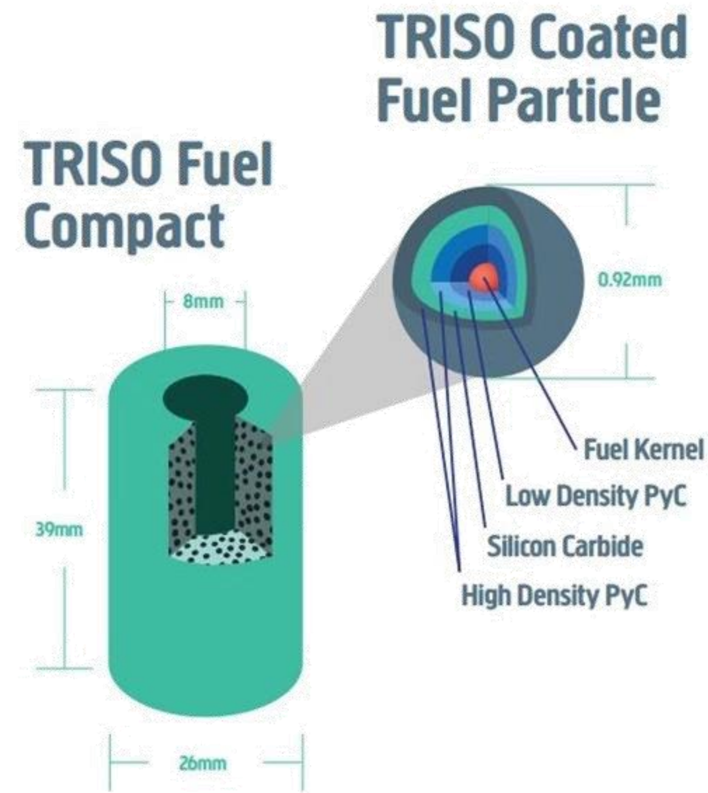




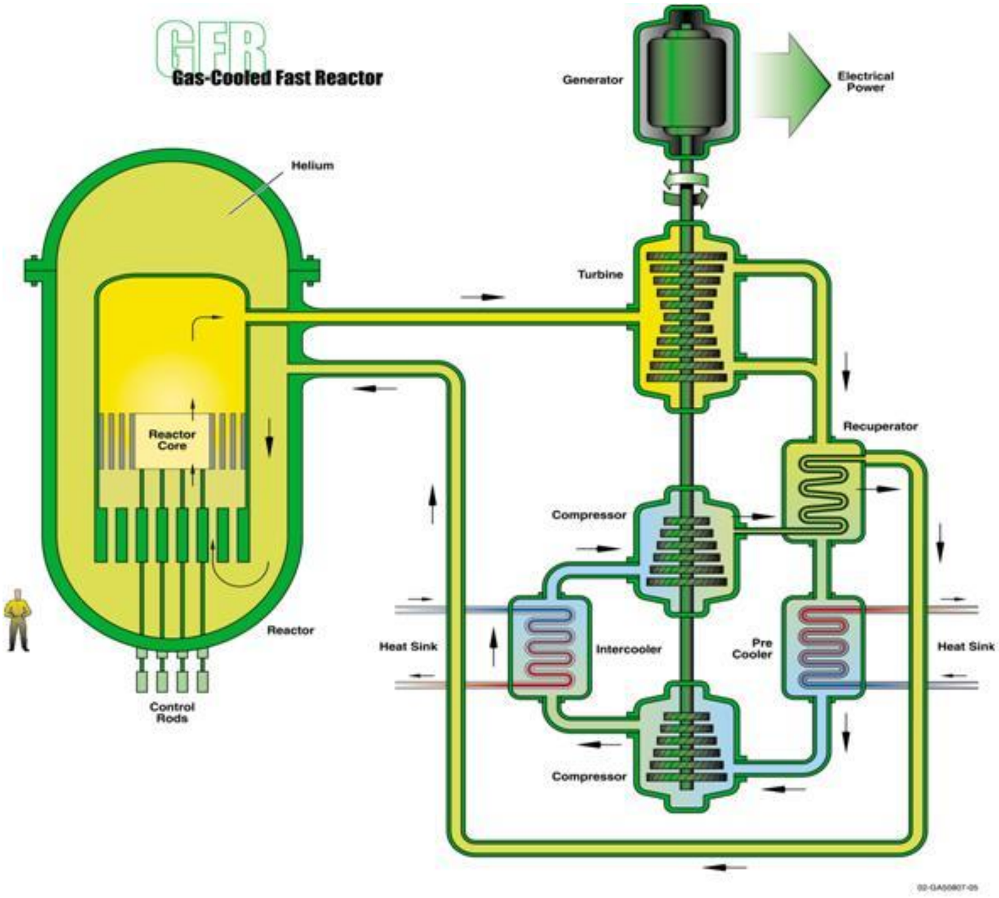
TRISO particles feature prominently in several advanced reactor designs

New Nuclear





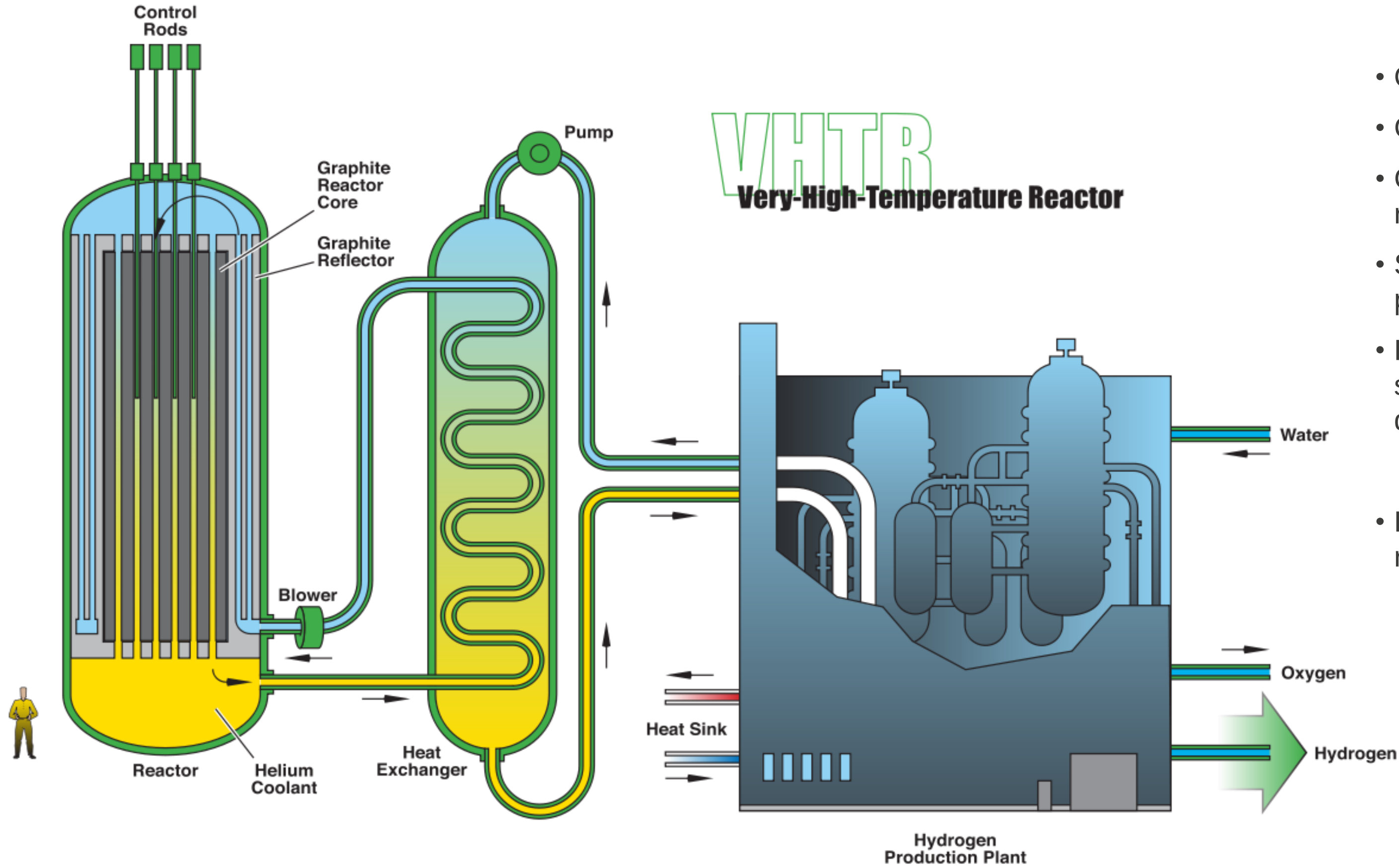
New Nuclear



- Outlet temps ~1000 °C
- Gas cooled
- Graphite moderated (thermal reactor)
- Solid TRISO fuel in pebbles or prismatic shape
- High temps allow for processes such as hydrogen production, desalinization

- Prior OPEX from experimental, research reactors
    - US (Peach Bottom, Fort St. Vrain),
    - Germany (AVR, THTR),
    - Japan (HTTR)
    - China (HTR-10)

New Nuclear



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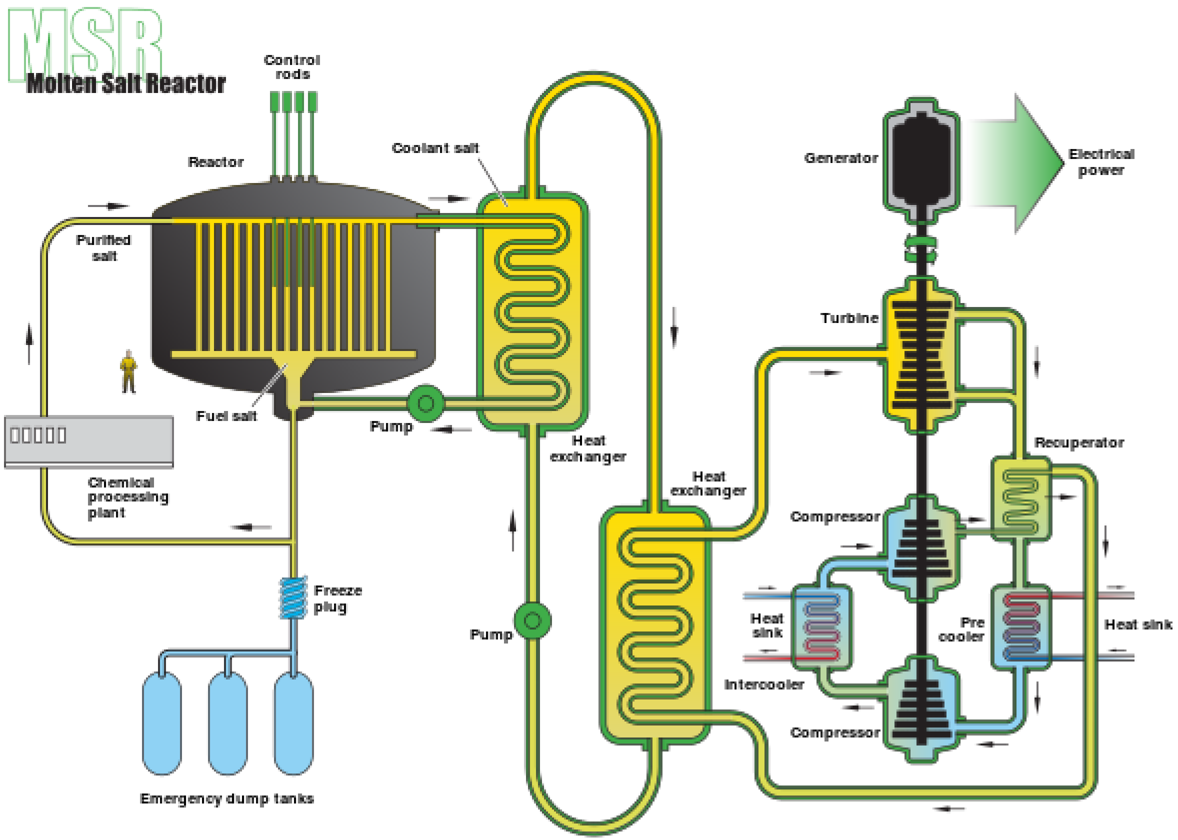
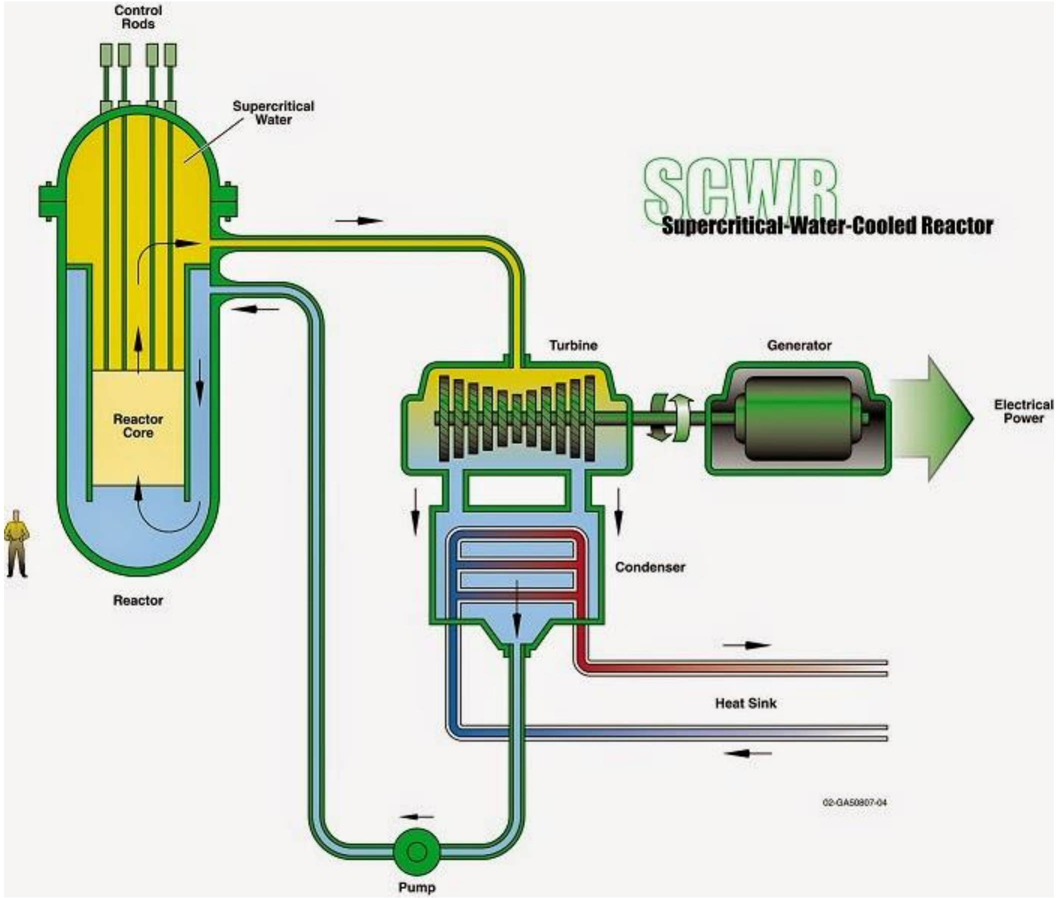
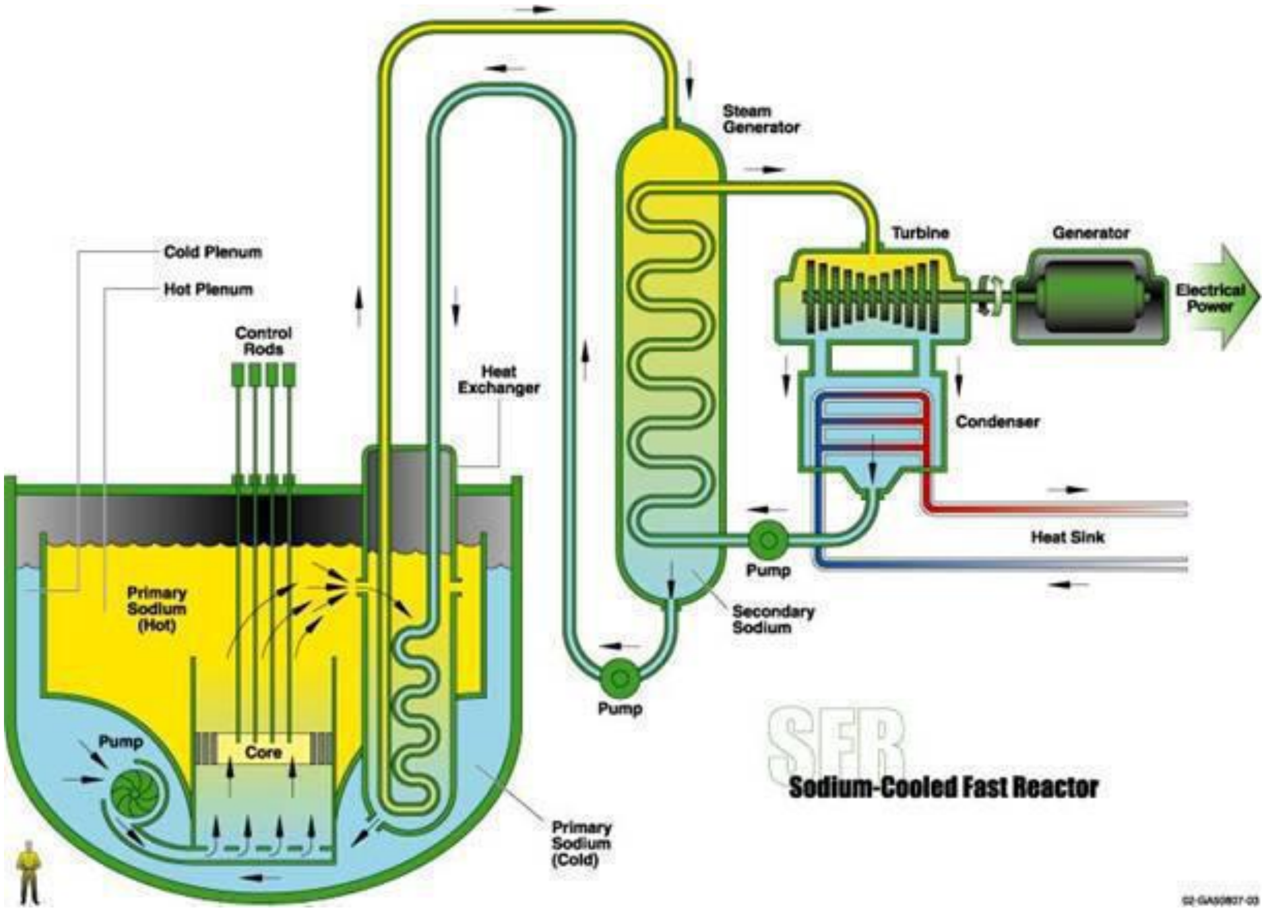


- Coolant is a molten salt
  - Flouride or Chloride salt
  - Fluorine-Lithium-Beryllium (FLiBe)
- Can have solid or liquid fuel
  - Liquid fuel can online reprocess
  - However, liquid fuel has modeling & safety considerations
  - Fuel can be Th, U, Pu
- Graphite moderated (thermal reactor)
- OPEX is limited

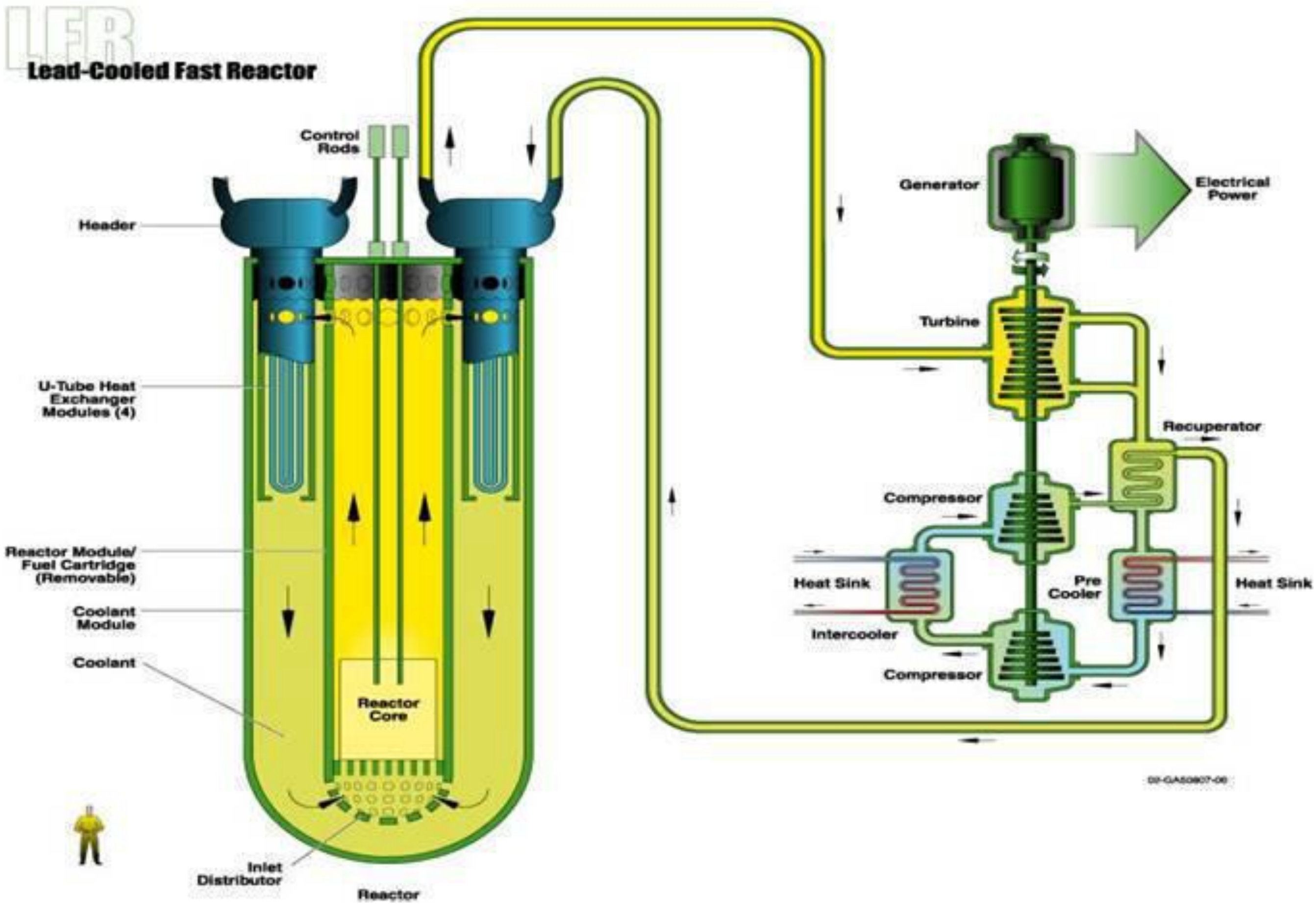


The term critical in this context refers to the critical point of water, and must not be confused with the concept of criticality of the nuclear reactor.

- Many aspects similar to LWR (fuel, water moderated & cooled)
- Doesn't need pressurizers, steam generators (PWR), or steam separators and dryers (BWR)
- High thermal efficiency
- High power density



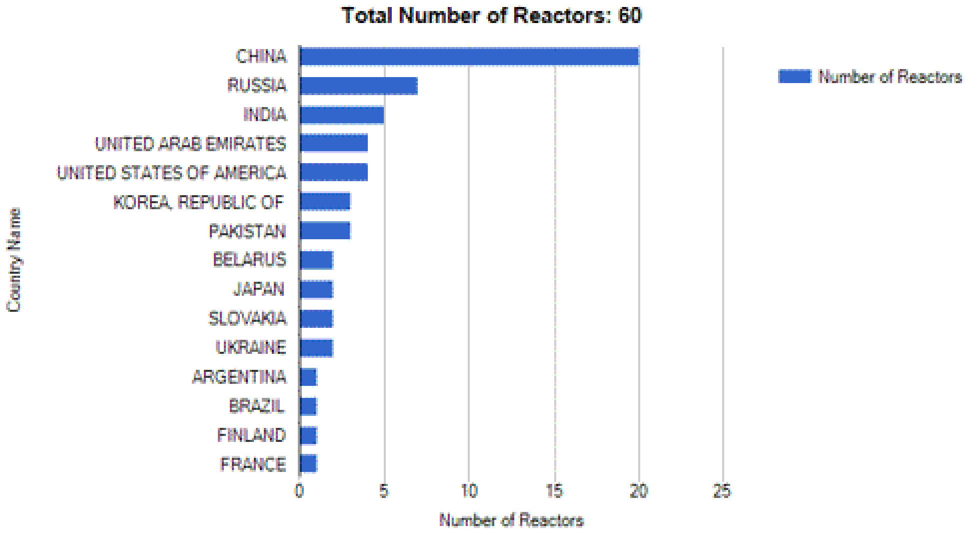
- Fuel is solid in pool of liquid sodium
- Sodium melts at low temp (371 K)
- Can use OPEX from around the world
  - Phenix, France
  - Monju, Japan
  - BN-600, Russia
  - Upcoming:
    - CEFR, China
    - PFBR, India

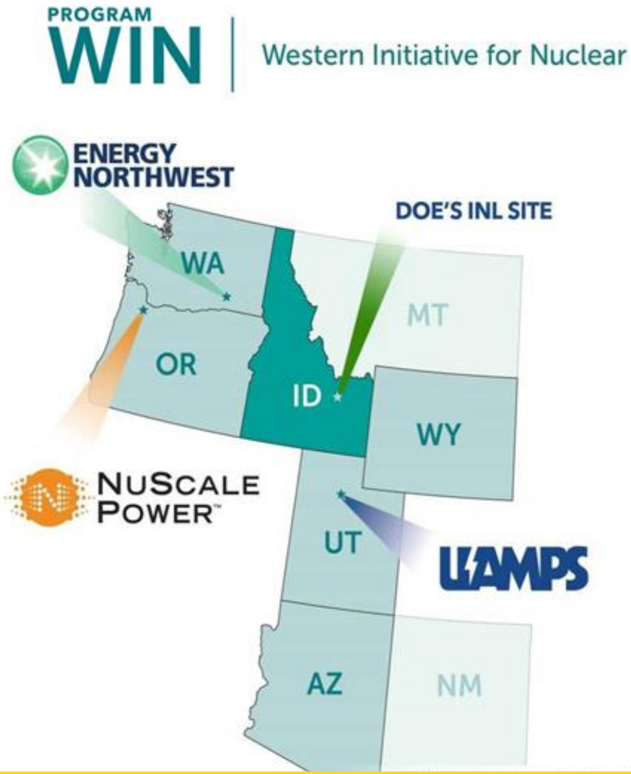


- Coolant is lead or lead-bismuth
- Metal or nitride-based fuel
- Lead is a good gamma shield
- Operating pressure quite low
- Lead does not react with water like sodium does
- Long refueling lifetime

- OPEX
  - Two LFR types in Russian subs in 1970s

New Nuclear





This is a take-away box

Los Alamos

NATIONAL LABORATORY

EST. 1943

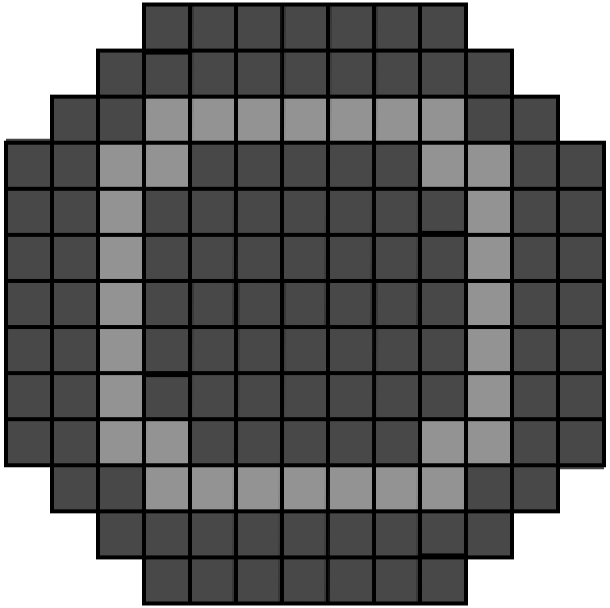
NNSA

National Nuclear Security Administration

Operated by Los Alamos National Security, LLC for the U.S. Department of Energy's NNSA

Shippingport cores

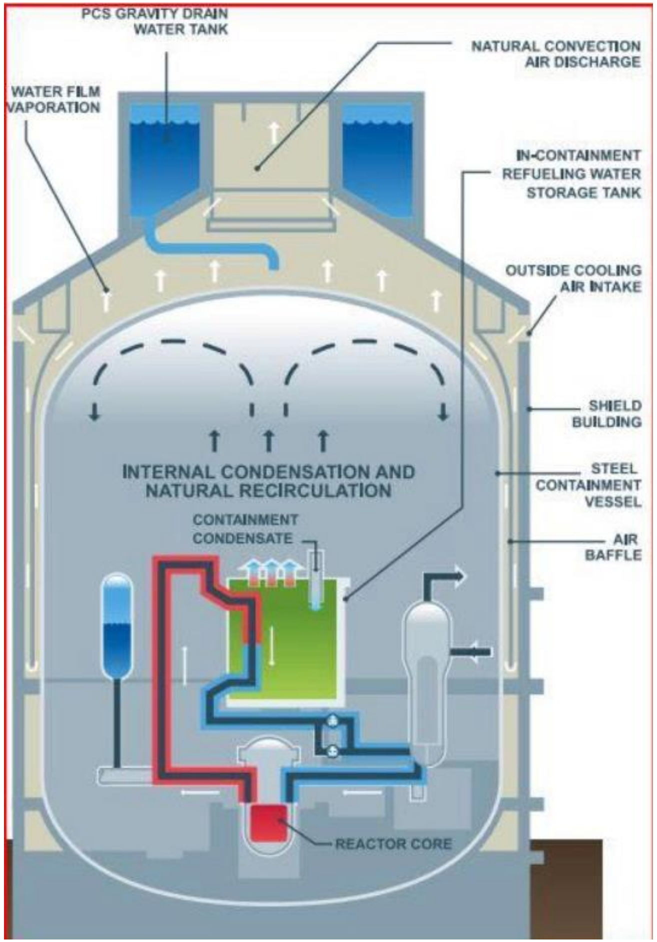
- **First Core**
  - Small seed
  - Highly enriched seed (93%)
  - Natural blanket
- **Second core**
  - Larger seed, more power
- **Third core**
  - Thermal breeder
  - Th and ^{233}U
  - 5–6% in seed
  - 1.5–3% in blanket

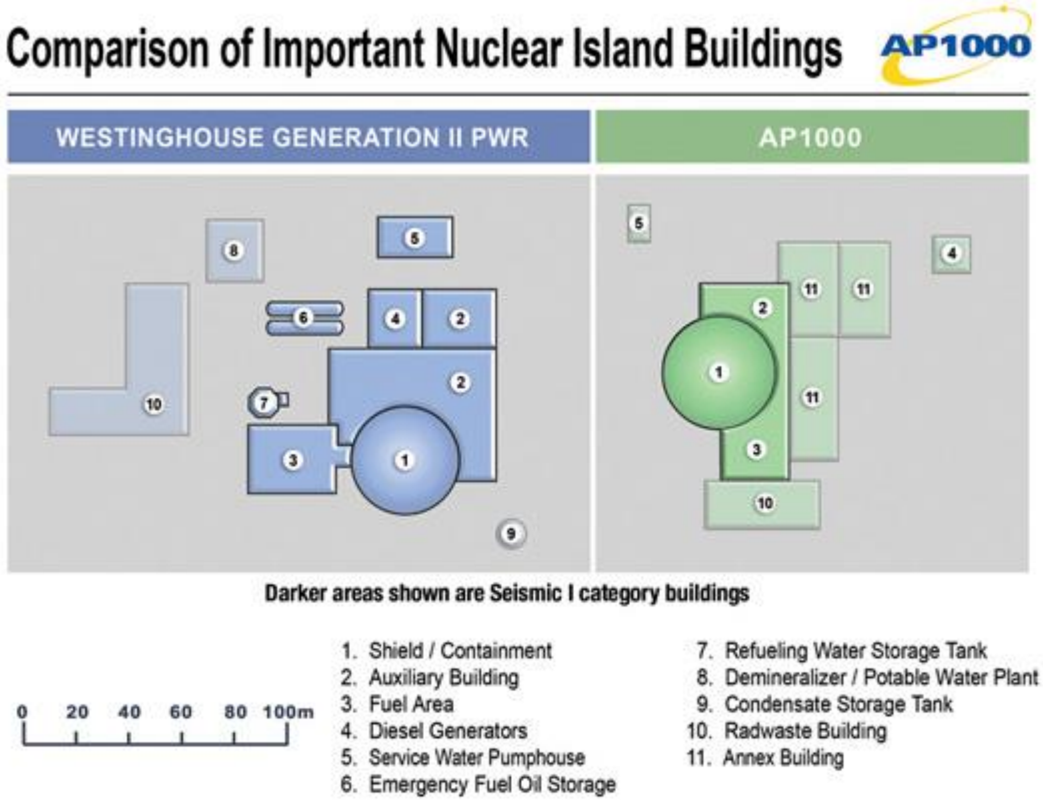


$$k_\infty = \eta \varepsilon p f$$

Symbol	Name	Meaning
η	Reproduction Factor (Eta)	$\frac{\text{neutrons produced from fission}}{\text{absorption in fuel isotope}}$
f	The thermal utilization factor	$\frac{\text{neutrons absorbed by the fuel isotope}}{\text{neutrons absorbed anywhere}}$
p	The resonance escape probability	$\frac{\text{fission neutrons slowed to thermal energies without absorption}}{\text{total fission neutrons}}$
ϵ	The fast fission factor	$\frac{\text{total number of fission neutrons}}{\text{number of fission neutrons from just thermal fissions}}$

AP-1000


PCS GRAVITY DRAIN WATER TANK
NATURAL CONVECTION AIR DISCHARGE
WATER FILM VAPORATION
IN-CONTAINMENT REFUELING WATER STORAGE TANK
OUTSIDE COOLING AIR INTAKE
SHIELD BUILDING
INTERNAL CONDENSATION AND NATURAL RECIRCULATION
STEEL CONTAINMENT VESSEL
CONTAINMENT CONDENSATE
AIR BAFFLE
REACTOR CORE


Comparison of Important Nuclear Island Buildings
AP1000
WESTINGHOUSE GENERATION II PWR
AP1000
Darker areas shown are Seismic I category buildings
0 20 40 60 80 100m
1. Shield / Containment
2. Auxiliary Building
3. Fuel Area
4. Diesel Generators
5. Service Water Pumphouse
6. Emergency Fuel Oil Storage
7. Refueling Water Storage Tank
8. Demineralizer / Potable Water Plant
9. Condensate Storage Tank
10. Radwaste Building
11. Annex Building

1. How many reactors are currently operating in the US?

A. 90

B. 99

C. 101

D. 104

2. What is the oldest <u>operating</u> plant in the U.S.?

A. Millstone 1

B. Browns Ferry 1

C. Oyster Creek 1

D. Dresden 1

3. Which nuclear plant around the world came online most recently?

A. Chashma Unit 3, Pakistan

B. Haiyang I Unit 2, China

C. Novovoronezh II Unit 1, Russia

D. Yangjiang I Unit 4, China

4. How many countries in Latin America have commercial reactors?

A. 0

B. 1

C. 3

D. 5

5. Which state has the most nuclear plants?

A. Illinois

B. Pennsylvania

C. Georgia

D. Ohio

6. Which state has the highest <u>percentage</u> of electricity from nuclear?

A. Illinois

B. New Jersey

C. Georgia

D. South Carolina

7. What is the capacity of the largest nuclear plant in the world?

A. 9,445 MW
B. 8,989 MW
C. 8,212 MW
D. 6,234 MW